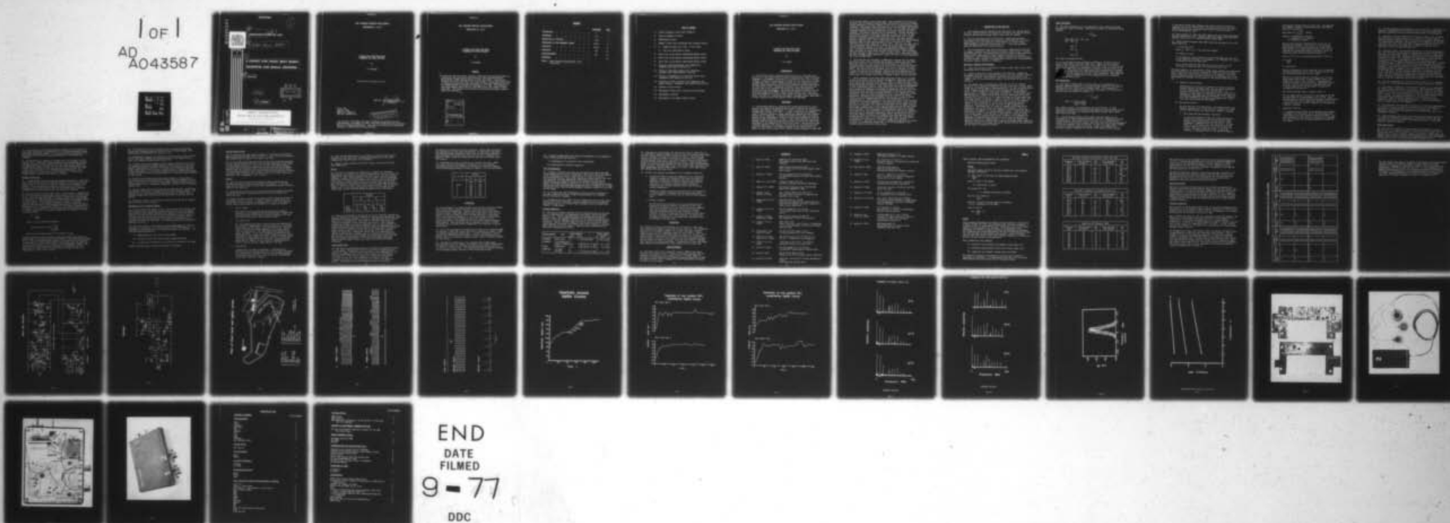
AD-A043 587 ARMY PERSONNEL RESEARCH ESTABLISHMENT FARNBOROUGH (EN--ETC F/G 6/2
A POCKET SIZE HEART BEAT RADIO TELEMETER AND SIGNAL DECODER.(U)
JUN 77 J B PECKHAM
UNCLASSIFIED APRE-MEMO-43/76 NL

1 OF 1
AD
A043587



END
DATE
FILMED
9-77
DDC

UNLIMITED

ADA043587

1

B.S.

9

rept.,

MEMORANDUM APRE No. 43/76

14

APRE-Memo-43/76

6

A POCKET SIZE HEART BEAT RADIO TELEMETER AND SIGNAL DECODER.

by

10

J. B. Peckham*

12 42p.

11

JUNE 1977

ARMY PERSONNEL
RESEARCH ESTABLISHMENT
MINISTRY OF DEFENCE
c/o Royal Aircraft Establishment, Farnborough, Hants

403 510

UNLIMITED

ARMY PERSONNEL RESEARCH ESTABLISHMENT

MEMORANDUM No. 43/76

A POCKET SIZE HEART BEAT RADIO TELEMETER AND SIGNAL DECODER

by

J B Peckham*

Received for printing 27.6.1977

Approved ______________ Director

Study: R26
Sponsor: DAHR
APRE File: 405/2/02
MOD File: 86/Res/1514

* At the time of writing, the author, sponsored by the Royal Aircraft Establishment, was engaged on a BSc 4 year thick Sandwich Course in Applied Physics at Brighton Polytechnic. This project was carried out during the industrial training period of his 3rd year.

ARMY PERSONNEL RESEARCH ESTABLISHMENT

MEMORANDUM No. 43/76

A POCKET SIZE HEART BEAT RADIO TELEMETER AND SIGNAL DECODER

by

J B Peckham

SUMMARY

A prototype heart beat radio telemetry system has been constructed which is suitable for use on soldiers negotiating the Army Personnel Research Establishment (APRE) Agility Course at their best speed. With only one telemeter in use at least 93% of the total number of heart beats made during an average two minute run time were detected. When two telemeters were in use simultaneously the detection efficiency fell to 63%. Interpolation of recordings however would count at least 99% of the total number of heart beats made. The design of the circuits is described and possible improvements are discussed.

CONTENTS

LIST OF FIGURES

ARMY PERSONNEL RESEARCH ESTABLISHMENT

MEMORANDUM No. 43/76

A POCKET SIZE HEART BEAT RADIO TELEMETER AND SIGNAL DECODER

by

J B Peckham

INTRODUCTION

1. The prototype radio telemetry system described in this report has arisen out of the Army Personnel Research Establishments (APRE) continuous programme of development in methods of recording the heart rate of active soldiers. Using electrocardiogram detection circuits previously developed at APRE (Amor 1972) a radio telemetry system has been constructed which operates within the Medical and Biological Telemetry waveband specified by the Home Office (1976). Subsequent sections of this report describe the circuits used in the telemetry system and the design considerations involved in their development. The system was intended primarily for use on soldiers negotiating APRE's Agility Course (Figure 3) at their best speed and examples of its use in this context are described. Since this project was part of a continuing development programme further improvements of both a specific and a more general nature are discussed.

BACKGROUND

2. Conventional methods of measuring the energy expenditure of active soldiers use respiratory apparatus which rather restricts the subject's activity and require a large number of staff to supervise the investigation (Haisman 1970, Crowdy et al 1971). In order to preserve an acceptable level of military realism in energy expenditure assessments less intrusive methods must be employed. A technique currently being used is one which depends on the relationship of heart rate and energy expenditure (Booyens and Hervey 1960, Bradfield et al 1969). This method has been reported by Haisman (1970) who used precalibrated subjects (ie their heart rates were determined in the laboratory for various work loads). The success of this technique depends to some extent on the accuracy of collecting the heart rates from the subject. For APRE's purposes it was required that the number of heart rates obtained from a subject should represent at least 99%

of the actual number of heart beats made. The requirement for monitoring the heart rate of subjects during routine activities or exercise to obtain energy expenditure or stress indexes is best met by electrocardiogram (ecg) telemetry. This method leaves the subject as free as possible and requires only limited supervision from Scientific staff. The two basic methods of telemetry suitable for this application are storage telemetry and radio telemetry, both methods having their own advantages. Storage telemetry is particularly useful for long term collection of heart rate but can make activity versus heart rate studies difficult unless some sort of event marking is included alongside recorded heart beat. The usual storage medium is magnetic tape. Such a system using the Oxford Instruments Medilog miniature tape recorder has been used over a 3 year period to study industrial work stress (Smith and O'Brien 1976). Work has also been carried out using similar tape recorders to study the energy output of Norwegian coastal fishermen (Rodahl et al 1972). An alternative method to beat by beat recording is the Socially Acceptable Monitoring Instrument (SAMI) which totalises the heart beats over the period of test. This instrument has been reported by Baker et al (1967) and Amor (1972); when used in 1966 and 1967 for APRE energy expenditure trials a 6% error in energy expenditure was found (Haisman 1970).

3. Circuitry has been developed at APRE which processes the ecg signal detected by three chest electrodes and produces a square pulse for every heart beat detected. The circuit has been designed to reject motion artifacts produced during exercise and a heart beat counter with a digital display has been constructed giving an error rate of less than 1% (Amor 1972). The counter and ecg processing circuits were designed to fit into a single box carried by the subject. However the power consumption was found to be high and the instrument suffered from the limitation that the subject had to be stopped every time a reading of heart rate was required.

4. Radio telemetry on the other hand allows heart beats to be recorded at some point remote from the subject and enables a continuous record of heart rate versus activity to be made. A number of commercial radio telemetry systems are available which transmit ecg's but these systems can cost as much as £1,000 per subject. They also suffer from a major disadvantage in that considerable motion artifact picked up by the chest electrodes when a subject is vigorously exercising is transmitted with the ecg. The presence of these artifacts in recordings made at the receiver can make interpretation of the trace extremely difficult if not impossible in some situations. Since the actual ecg pattern is not required in energy expenditure assessments the processing circuitry used in Amor's counter offers a means of transmitting artifact free signals which can be unambiguously and readily decoded at the receiving stage for use in energy expenditure and stress assessments. By producing a square pulse from the decoder for every heart beat detected missed beats due to signal drop-out may easily be counted in on a hard copy recording from the decoder output. Using radio telemetry some of the problems associated with the counter can be overcome. Power consumption is considerably reduced by counting the pulses at the receiving stage rather than on the man and the subject's heart rate may be monitored continuously without hindering his activity. A miniature Smith and Nephew Ltd transmitter has been used with Amor's ecg processing circuit on very active Royal Navy Field Gun Team members to transmit heart beats over a 20m range. (Amor 1975, personal communication). The need for a greater transmission range and the ability to decode the transmitted signals has led to the development of the telemetry system described in this report.

DESCRIPTION OF THE CIRCUITS

5. The telemetry system consists of two main parts, the ecg processing circuits, audio oscillator and transmitter carried by the subject and the receiver, decoder and recording device remote from the subject.

6. The ecg processing circuits (amplifier, trigger and monostable oscillator), audio oscillator and transmitter are mounted on two circuit boards (Figure 13) and enclosed with the battery in a 100mm x 50mm x 25mm high-impact polystyrene case (Figure 14). A three pin polythene socket is provided for the electrode inputs.

7. The ecg detected by thee chest electrodes is amplified and then used to trigger a monostable vibrator which produces a square pulse for every detected heart beat. This square pulse is used to gate an audio oscillator which frequency modulates the radio frequency carrier wave from the transmitter. Each transmitter audio signal is detected by an FM receiver and then decoded to produce a 5V square pulse suitable for driving analogue recorders, digital counters or ratemeters.

Amplifier, Trigger and Monostable

8. Since this circuit is described in detail by Amor (1972) only a brief description will be given here.

9. Figure 1 shows the circuit diagram of the amplifier, trigger and monostable which have been modified from Amor's $\pm$ 5 volt version to run off a single 9V battery. The potential divider R1 and R2 provides a 4.5V 'common' rail for the differential inputs, thus avoiding the need for two batteries.

10. The signal from the differential amplifier is fed via 'emitter followers' to an operational amplifier (op amp) which gives a single ended output with an overall gain of approximately 50. All the resistance values of the trigger and monostable have been increased about ten times over those of the 5V version to reduce power consumption. The monostable multivibrator is triggered by swinging the collector of TR9 negative with TR8 and produces a pulse of some 150 ms duration determined by the time constant (C13 x R23 x $\log_e 2$). A typical ecg wave at the post amplification stage (Figure 5b) may have a 'QRS' wave of 800 mV (peak) with a 'QR' time interval of 20 ms giving a gradient of 40V/s. Since the charging current of C13 through R23 is 1.9 mA, this will oppose any negative impulse of less than 19V/s on the collector of TR9 triggering the monostable. This means that 'T' waves for example which might have a gradient of only 0.5 V/s would not trigger the monostable. Once the monostable is triggered it will not respond to further signals for the duration of the pulse. C12 and R19 with the emitter - base diode TR7 act as a voltage clamp. Since the base of TR8 requires a positive going pulse to produce a negative pulse at the collector, for triggering the monostable, a monitor output is provided at the post op amp stage to check the polarity of the QRS complex. If the electrode leads to the amplifier input become reversed and a negative going QRS complex appears at the monitor output a reversing lead may be inserted between the electrodes and the input to change the polarity.

Audio Oscillator

11. The audio oscillator is of the phase shift type, phase shift being produced by a "twin T" network. Oscillation frequency is determined by the equation

$$f = \frac{1}{2\pi RC}$$

where $R30 = R29 = R31 = 2R$
and $R28 = \frac{R}{3}$

$C18 = C$

$C17 = \frac{C}{2}$

$C19 = 3C$

the output is adjusted by R26.

12. A $0.1\mu F$ capacitor C16 provides ac coupling to the drain of the P channel Field Effect Transistor (FET) TR12. Gating of the oscillator output to the transmitter is effected by this FET. With zero volts on the gate the FET provides a low resistance to ground for the ac output of the oscillator. When the positive going pulse from the monostable is present at the gate the FET has a very high drain-source resistance thus allowing [illegible] signal from the oscillator to pass to the transmitter. This signal is [illegible] to the emitter-feedback loop of the transmitter where it frequency [illegible]lates the carrier wave.

The Transmitter

13. The radio frequency (RF) oscillator used in the transmitter is a resonant feedback oscillator of the Colpitts type similar to that used by McGinnis and Brown (1966) cited by Mackay (1968). The frequency of oscillation (f) is determined by the series combination of C22 and C23 in parallel with the inductor L1 (Figure 1).

$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$\text{where } C = \frac{(C22) \times (C23)}{(C22) + (C23)}$$

The feedback fraction is determined by the ratio C22/C23. In this particular transmitter the oscillator was required to provide an RF carrier wave within the Medical and Biological Telemetry waveband (Home Office 1976) 104.6-105.0 MHz.

14. A square spiral printed circuit copper coil was chosen for the inductance L1 to obtain maximum mechanical stability, compactness and ease of reproduction. Wire wound coils of the order of 1 cm diameter only require a few turns to produce the small inductance required to provide resonance at 100 MHz and therefore would be difficult to mount in a small space in such a way as to eliminate vibration effects. Square coil geometry was initially chosen to simplify the artwork of the printed circuit boards.

It was also envisaged that tuning of the circuit would be achieved by "tapping" the coil at various points along the inner turn of the spiral thus avoiding variable components which could be interfered with or altered by mechanical shock.

15. The properties of thick film flat spiral coils have been investigated (Corkhill and Mullins 1969), (Barnwell 1970) and design curves have been produced with the aid of a computer program (Green 1971).

16. Grover (Mullard Research Labs 1965) gives the inductance L of a flat square spiral as

$$L = 0.001\ N^2(r_o\ K)P$$

where $r_o = \sqrt{2}\ a$, (a, is the mean side length)

N = number of turns

K is a numerical factor between 0.8 and 0.9 dependent upon the ratio of the conductor thickness to the diameter $2\ r_o$ (diameter of a circle circumscribed about the mean turn).

P is a factor dependent upon the ratio of C/2a, where C is the difference between the radii of the outer and inner turn.

From this formula or by using Green's design curves suitable coil geometries can be obtained for the required inductance. However two major factors must be taken into account when selecting the coil geometry. The first is the consideration that the coil also acts as the radiating body of the electromagnetic radiation and the second is the quality factor (Q) of the coil.

(1) Radiation considerations

Assuming that the coil can be treated as a series of Herzian dipoles (Glazier and Lamont 1958) then the power radiated is directly proportional to the coil circumference. It therefore follows that the radiating efficiency of the coil is dependent to some extent on its geometry and is best when the circumference approaches half the wavelength of the radiation. Since the wavelength at 100 MHz is approximately 3m a large coil would favour radiation efficiency.

(2) The Quality factor Q

The Q of the coil is an indication of how sharply defined the resonant frequency will be when the coil is placed in a tuned circuit, and its value will depend upon a number of factors.

a. Skin depth and high frequency resistance

At very high frequencies (VHF) the current flowing in a conductor concentrates at the surface and the current density decays exponentially from the surface. This phonomena is commonly called the skin effect. The skin depth (δ) is the point within the conductor where the current density has fallen to 1/e of its value at the surface. Related to this skin effect is the high frequency ac resistance (R_{ac}) of the conductor which in

some measure determines the Q of the coil. Assuming that the classical formula for skin depth holds for a metal/glass fibre interface.

Skin depth (δ) $= \sqrt{\dfrac{\rho}{\pi \mu f}}$ Meters

where ρ = resistivity of conductor
μ = permeability of conductor
f = frequency in Hertz.

Now the high frequency resistance(R_{ac}) of the coil is directly proportional to its length (l) and inversely proportional to the cross sectional area of the "skin". This implies that a significant decrease in R_{ac} will be observed with increasing conductor thickness (up to 2δ) increasing width and also decreasing length (l).

The Q of the coil is inversely proportional to R_{ac} viz:

$$Q = \frac{2\pi fL}{R_{ac}}$$

(L = inductance)

From this equation it can be seen that the Q is therefore directly proportional to the "skin" cross sectional area and inversely proportional to coil length.

Therefore increasing conductor thickness up to 2δ and a small aspect ratio favour a high Q (aspect ratio = coil length $\div$ the width of the conductor). Increasing the conductor thickness beyond 2δ does not appreciably affect the Q of a coil if the conductor cross sectional area is large compared with its skin depth (δ) since for a rectangular cross section:

Skin cross sectional area $\simeq$ conductor width x 2

For the copper printed circuit coil resonating at 100 MHz the skin depth (δ) is approximately 1.3×10^{-5}m. Since standard printed circuit conductor thickness is approximately 3.3×10^{-5}m (ie $> 2\delta$) no significant increase in the Q of a printed circuit coil would be expected by increasing the conductor thickness.

b. Capacitance effects

At frequencies above 80 MHz the predominant loss mechanism is thought to be dielectric due to the distributed self capacitance of the coil (Corkhill and Mullins 1969). The self capacitance of the coil is a function of its geometry and will increase with decreasing separation between the coil turns.

17. From the foregoing considerations it can be seen that in choosing coil geometry a compromise has to be made between a large coil circumference favouring radiating efficiency and small aspect ratio favouring high Q.

18. Initially a coil was fabricated from adhesive copper tape to explore the feasibility of using a spiral coil. Since only a limited area of circuit board was available a coil of three turns occupying 1 cm^2 was made with approximately 1mm tape width and spacing. By tapping along the inner turn of the coil the circuit was made to resonate within the 104.5 to 105.0 MHz region with a 10 pf and 47 pf capacitor in series in the oscillator circuit (C22 and C23 Figure 1).

19. A printed circuit coil was then made having 3 turns and occupying 1.3 cm^2. The tape width was 1mm and the spacing between turns 0.75mm. Some difficulty was experienced however in tuning the oscillator by tapping the coil along its inner turn. Although oscillations at 104.6-105 MHz were obtained the range of the transmitter was considerably reduced over that of the previous one. It was suspected that the oscillator was not resonating at its fundamental frequency in the required waveband. In order to simplify tuning, a fixed coil was used for the inductance L1 and C22 was replaced by a variable capacitor (15 pF Tetfer trimmer manufactured by Jacksons). Using the capacitor as the tuning element the oscillator was successfully made to resonate at its fundamental frequency in the 104.6 to 105.0 MHz band. Several trimmable capacitors are available with Q's of over 500 and at the time of writing two types have been successfully tried. One is the 8mm Tetfer trimmer made by Jacksons and the other, also made by Jacksons, is the non-rotating piston trimmer 5pF (used in parallel with a 0.8 pF fixed capacitor) with an air dielectric.

20. With this transmitter an effective radiated power (erp) of approximately 600 nW at 104.8 MHz has been achieved giving ranges of up to 100m.

21. The frequency stability of the oscillator depends on the temperature and supply voltage variations of the circuit. Major temperature changes are compensated for by the use of diodes D1 and D2 (Figure 1) and voltage stability is provided by an integrated 5V regulator supplying the transmitter circuit. The frequency variation of the oscillator has been found to be 0.008 MHz per degree centigrade rise in temperature (5-35°C temperature range) for battery voltages of 9-6 V. Below 6V battery voltage the output of the 5V regulator begins to fall thus introducing a major frequency shift in the transmitter.

22. With modulation from the audio frequency oscillator side band emission is contained within a 0.05 MHz band width for up to 20 dB attentuation and within a 0.1 MHz band width for up to 60 dB attentuation. The unmodulated carrier wave is attenuated 50 dB 0.05 MHz either side of the fundamental frequency.

23. This performance falls within the Home Office provisional specification (1976) for "wideband" transmitters. Full details of all the test procedures and results including a spectrum analysis over a 0-1000 MHz range are included in Annex A.

Power Requirements

24. Initially a 15V version of the telemeter was designed to run off a B121 15V dry cell (readily available). However the current drain on the battery was found to be too great to give an acceptable working life. An average life of 3 hours continuous running was obtained. This version was found to draw a total of 10.8 mA. The transmitter and 5V voltage regulator drawing 10.15 mA, with the remaining circuits drawing 0.65 mA.

25. As the battery life was provisionally required to be at least 30 hr other power sources were investigated and a 9V alkaline-manganese battery the MN 1604 was finally chosen. A zinc carbon battery and a mercury cell (nominally 8.4V) with similar physical dimensions to the MN 1604 are available.

26. The MN 1604 has a capacity of 525 mAh with a cut off point of 4.8V (750Ω at 20°C). Since the voltage regulator of the transmitter requires a minimum voltage of 6V the effective cut off point for the battery in this application must be around 6V. From the manufacturers data a life of about 28 hr at 20°C is to be expected with a cut off point of 6V and current drain of 15 mA at 7.5V (discharge through 500Ω load). The current drain of the 9V version of the telemeter is 7.3 mA and so an estimated 50-60 hr battery life should be obtained.

Decoder and Receiver

27. A Grundig YB210 FM receiver having an input sensitivity of 3-4μV was used as the receiver and the decoder was designed to plug in to the tape output socket of the receiver. Figure 2 shows a circuit diagram of the decoder. At the receiver each heart beat is detected as a burst of sinusoidal audio oscillations of some 150 ms duration with a frequency determined by the audio oscillator in the heart beat telemeter.

28. The audio signal from the tape output of the receiver is amplified by an LM 741 op amp at the input stage of the decoder to give an overall gain of 100. When the amplified signal exceeds the output sum of the op amp, determined by its supply voltage, it becomes squared off and approximates to a square wave. The output from the op amp is then fed through a 4.7μF coupling capacitor to an external component. Values are given in manufacturers data sheets (LM567 National Semiconductor and XR-567 Rastra Electronics Ltd). The detection frequency of the decoder (square wave or sinusoidal) is set by R8 and C7 and the detection band width by C5 at pin 2. Values of R8 and C7 for a given frequency may be determined from the following formula

$$f_o = \frac{1}{R8C7}$$

where f_o is the detection frequency

$$\text{also Band width} = 1070 \sqrt{\frac{V\,in}{f_o\ C5}}$$

where Vm is the input signal to the decoder in V_{rms}.

Constant band width operation requires that the decoder input should be greater than 200 mV (rms) whence the band width is controlled by the product of f_o and C5. By amplifying the signal to the decoder as described above a high signal level can be maintained at the decoder input even when the receiver output is low (ie at the limit of the transmitter's range). The tone decoder is protected from overloading by the squaring off of its input when the output signal from the receiver is high (ie when the transmitter is close to the receiver).

29. C4 connected from pin 1 to ground forms a low pass post detection filter which eliminates spurious outputs from out of band signals. The manufacturer's recommendation is that C4 $\geqslant$ C5.

30. Considerable 'chatter' was evident in the output with a value of C4 of 4.7μF, this was eliminated by feeding back some of the output to pin 1 with a 1μF capacitor between pins 1 and 8 (C3).

31. A binary logic output appears at pin 8 giving a positive level set by the supply voltage when no inband signal is present and a near zero level when an inband signal is present. The output of the decoder is inverted using a monolithic inverter to give a stable positive 5V square pulse for every inband signal. A 5V regulator supplies the tone decoder and inverter so that a stable 5V output is obtained suitable for driving digital counters or rate meters.

32. Further tone decoders may be fed from the output of the op amp to provide detection at other frequencies if more than one telemeter is to be used with one receiver. To date a 'two channel' version has been built to decode signals from two telemeters transmitting different audio frequencies. (Fig 15, 16).

33. The two channel decoder has been used successfully with a Devices Ltd two channel ecg recorder, a digital rate meter and a digital counter. The output pulse of the decoder is sufficiently 'clean' and chatter free to reliably trigger logic circuits such as encountered in counters and rate meters.

34. The whole circuit of the decoder is powered by an MN 1604 9V alkaline battery as used in the telemeter.

Performance of the Telemetry System

35. The electrodes used during trials of the telemeter were the chlorided silver type held in a polythene cup and attached to the chest by double sided adhesive rings (Becton-Dickinson Ltd disposable electrodes) IMI low chloride electrode gel was used as the skin-electrode interface and the electrode site was cleaned and abraded as described by Shackel (1959) to decrease skin-electrode resistance. The important considerations in electrode selection and attachment for exercising subjects are discussed by Hamish et al (1972).

36. Since the success of any method of electrocardiography is critically dependent on the quality of electrode placement great care should be exercised in the preparation of the skin and placement of electrodes. The electrode positions used were

(i) approximately at the centre of the sternum

(ii) around the lower end of the sternum (common electrode)

(iii) at about the V4 position over a rib and at the apex of the heart.

Slight variations may be required from subject to subject.

Agility Course Trials

37. The telemeter has been used on a number of occasions by subjects on APRE's agility course (Wynne 1974) (Figure 3). Heart rates were monitored and recorded from the centre of the course each time.

38. In all trials electrodes were fitted in the chest positions described earlier, and the polarity of the 'R' wave checked using the monitor output of the telemeter (Figure 5b). Where the 'R' wave was negative going a reversing lead was inserted between the electrode lead and the telemeter. Adhesive tape was placed over the electrodes to help keep them in place. A heat writing galvanometer chart recorder (Devices Ltd) was used to record the output from the decoder and the heart beats of the subject were also monitored on the loudspeaker of the receiver.

Trial 1

39. In this trial the subject wore standard combat clothing and the telemeter was placed in the breast pocket of his jacket. It was also tried in his trouser pocket, but was found unsatisfactory since it bounced around in this position.

40. Recording was started as the subject began his run around the agility course and the various obstacles were marked on the recording as he negotiated them.

41. Figure 4a shows a section of the trace produced during the subject's progression around the course. A number of gaps or 'missed beats' can be observed, on this occasion they amounted to 7% of the total number of beats. These missed beats can be attributed to a number of factors.

a. Loss of signal

This could be caused by the subject going out of range or screening of the transmitter by various obstacles. Signal loss was particularly noticed when the subject negotiated the zig-zag trench constructed of thick wooden sleepers.

b. Low signal level

On a few occasions the signal could be heard very faintly over the receiver's loudspeaker but was not detected by the decoder. If the signal to the decoder falls below 200 mV rms the band width of the decoder becomes dependent on the input signal level (see Section II). The band width now decreases as the signal decreases. If the audio frequency has shifted or the band width of the decoder has 'skewed' from the original centre frequency the audio signal could fall outside of the detection band width and therefore not be detected. Alternatively the signal may be 'inband' but fall below the minimum detection level of the tone decoder (approximately 25 mV rms).

c. Interference

Although 104.6-105 MHz is designated the Biological and Medical Telemetry waveband other users of this band (eg police) have higher power transmitters and on some occasions stronger transmissions than the radio telemeter caused a "blanketing" of the radio telemeter's signal.

42. Even with 7% missed beats it can readily be seen that these can be counted in on the 'hard copy' recording where gaps occur in the trace (assuming the 'missed beats' are not genuine!)

43. Figure 6 shows a graph of heart rate versus time derived from the trace (Figure 4a).

Trial 2

44. In order to determine the feasibility of running two telemeters simultaneously two subjects, FL and PC wearing NBC protective clothing were telemetered. Each subject completed the course twice, each time wearing different clothing. Electrodes were fitted as before and the telemeters, both tuned to the same radio frequency, were placed in the breast pockets of the subject's shirts. Heart rates were recorded while the subjects were resting before beginning the course and after completing the course. Figure 4b shows a section of one of the traces obtained. The incidence of 'missed' and 'extra' beats are tabulated below as a percentage of the total number of beats recorded whilst the subject was on the course.

	SUBJECT			
	PC		FL	
	1	2	1	2
Total	575	476	454	532
Extra	0	0.4%	0.2%	0.6%
Missed	22%	37%	4%	4.3%

45. During the recordings of subject PC the second telemeter was also in range and drifting of the first telemeter's frequency was experienced. This frequency drifting was thought to be due to some combining of the carrier waves from each transmitter. The degree of drifting varied with the telemeter's proximity to each other and the receiver. This frequency drifting was thought to be partly responsible for the high incidence of missed beats during subject PC's recording. Even so interpreatation of the results was still possible with as many as 37% missed beats and Figure 7 shows a graph of heart rate versus time derived from these results. During the recording of subject FL's heart rate as he negotiated the agility course the first telemeter was out of range and no interaction was observed. In this case the number of missed beats is much lower and they are probably attributable to the effects mentioned previously. Figure 8 shows a graph of heart rate versus time derived from these recordings.

5 Mile March Trial

46. Two subjects wearing NBC protective clothing were telemetered during a 5 mile march. The subjects covered the 5 miles by walking around a circuit six times. Heart rates were recorded at the commencement of the walk and on subsequent laps as the subjects passed the starting and finishing point. Each subject stopped for temperature measurements to be made on each lap. The telemeters, both tuned to the same frequency were placed in the breast pocket of each of the subject's shirts. Interaction of the two telemeters did not occur during

the march as the subjects were well separated. However some drifting of the frequencies did occur when they were both in range before the march. Although the subjects perspired a great deal the electrodes remained in place throughout the march which took about one hour to complete. No 'missed' or 'extra' beats were found when the subjects were within 50m of the receiver.

47. Recordings were made on a Devices Ltd recorder as before. Heart rates taken from the recordings are presented below and represent instantaneous heart rates obtained by measuring the interbeat distance on the recording paper Figure 5a shows an example of the traces obtained.

NO. OF LAPS	SUBJECT	
	PC	RC
	b/min	b/min
Start	109	109
1	150	120
2	150	120
3	150	120
4	133	120
5	133	120
6	133	120

DISCUSSION

48. The employment of a simple Colpitts type oscillator with an integral aerial rather than a crystal controlled oscillator has provided a relatively cheap transmitter. However, since this type of oscillator operates within a "wide band" specification (Home Office 1976) only one channel is possible within the 104.6-105 MHz band width. This means that if more than one transmitter is to be used within this band width on/off switching of each transmitter would be required to avoid interfering effects of more than one RF carrier wave being transmitted simultaneously. This switching could be achieved by direct or remote techniques thus allowing several transmitters to be switched on and off sequentially.

49. One of the advantages of transmitting a single audio frequency signal to represent a heart beat rather than the more complex ecg signal is that it minimises transmission distortions. A further advantage is that an unspecialised FM receiver may be used to receive the transmission and a decoder used as the interface between analogue records or digital counters and rate meters.

50. Although the limitations of the equipment make 'missed beats' inevitable when used for example on an agility course these 'missed beats' can easily be counted in on a hard copy particularly where only one or two beats at a time are lost. For applications where continuous recording is not necessary digital counters or rate meters may be used.

51. A number of improvements and further developments to the transmitter could be made however and these are:

(i) Optimisation of transmitter coil configuration.

(ii) Optimisation of variable capacitor.

Coil Configuration

52. A number of printed coils have now been produced by Radio Dept RAE using standard printed circuit technology. These coils have been produced in two thicknesses 1.3 thou (1 oz/sq ft) and 2.7 thou (2 oz/sq ft). Variousconfigurations of tape width, spacing and overall area of coil have been produced. Circular spirals have also been made in the hope of determining whether higher Q values can be obtained with such coils. Bamwell (1970) has reported Q values of up to 150 at 120 MHz using circular spirals and thick film technology whereas work done by Corkhill et al (1969) with square spiral inductors gives maximum Q values of around 60 in the 100-140 MHz range.

53. It is hoped that the configuration of the coil can be optimised to give good range and Q values, a high Q being desirable for a sharply defined oscillation frequency.

54. By mounting the coil remote from the transmitter on the circuit board containing the audio oscillator a larger surface area would be available enabling the coil to be increased from its present size to around 20 mm diameter or 20mm square.

Variable Capacitor

55. The type of variable capacitor used in conjunction with the coil has yet to be optimised for low temperature co-efficient, high Q and small physical size. Several capacitors have been obtained and two are at present in use. The required capacitance in the Colpitts oscillator is between 7-15 pF for inductance values of 0.15 to 0.3μ H (105 MHz resonant frequency). Smaller variable capacitors can be used in parallel with a fixed capacitor since only fine tuning of the radio frequency is required. Characteristics of the four types of capacitor under consideration are shown below (Manufacturer's data).

MANUFACTURER	TYPE	CAPACITANCE Min	Max	Q	TEMP. COEFF ppm/°C
JACKSONS	8mm Tetfer	2	15	>1000 @ MHz	+ 250 ± 200
JACKSONS	Air Dielectric Piston Trimmer	0.5	5.0	>1000 @ 20 MHZ	+ 50 ± 50
OXLEY	PTFE TUT/7	0.5	7.0	>2000 @ 100 MHZ	0 ± 150
STEATITE	7s TmKo Ceramic	3	9	>1000 @ 100 MHz	+ 75 - 125

56. Although the time available for this project has not permitted, it was hoped that a portable digital counter or rate meter would be made which could be triggered directly from the decoder output. The decoder has however been used on a number of occasions to directly drive a mains operated digital counter and a rate meter (Venner Electronics Ltd Digital Counter TSA 6635/2 and Orbital Controls rate meter). Many analogue and digital circuits have been reported for beat to beat heart rate measurement giving so called "instantaneous" heart rate (Atherton 1975, Caldwell et al 1970, Czekayewski and Tove 1964, Gordon et al 1972, Green 1967, Ludwig 1967, Mackay 1963 and Murphy 1969).

57. Further, more general developments of the telemetry system are:

a. Inclusion of skin or mean skin temperature into transmitted signal by varying the frequency of the audio oscillator in response to temperature variation detected by a thermistor. Some form of frequency to voltage converter would then be required at the receiving stage to convert frequency variations into voltage variations which could be used to display temperature.

b. Design of a crystal controlled oscillator for the transmitter to provide greater frequency stability which would allow several channels to be fitted into the 104.6-105 MHz frequency band.

c. Storage telemetry

The reliability and accuracy of the ecg processing circuit presents an attractive method of producing artifact free heart rate information for long term recording onto magnetic tape using miniature recorders. Using audio frequency recorders the signal from the audio oscillator of the telemeter could be recorded and later decoded on play back of the tape to produce a hard copy recording. By varying the frequency as described in (a) temperature information could be recorded at the same time.

CONCLUSION

58. Within the limited time available for this project a heart beat radio telemeter and signal decoder have been constructed. The transmitter has an erp of 600 nW and a range of up to 100m. The mean frequency stability over a 5-35°C temperature range is 0.0086 MHz/°C. Using a signal decoder after the receiving stage each heart beat detected can be counted directly using digital techniques or recorded on an analogue chart recorder. From the trials conducted with this equipment on APRE's agility course the number of 'missed' beats has been found to represent less than 7% of the total number made. Interpolation of chart recordings made rendered at least 99% of the total number of heart beats made.

ACKNOWLEDGEMENTS

59. The author would like to thank Mr A Amor of APRE for his advice throughout this project and Mr V Tippins of Designs Department RAE for producing the artwork for the printed circuits. Finally thanks are expressed to Radio Department and Engineering Physics Department of RAE for making available their equipment for the RF measurements presented in Annex A of this report.

REFERENCES

1. Amor A F (1972) — APRE Research Memorandum 18/72
Performance tests of the SAMI heart beat totaliser.

2. Amor A F (1972) — APRE Technical Memorandum 42/72
An all solid state electrocardiographic heart beat counter.

3. Atherton J (1975) — Med Biol Engng Sept 1975 pp 635-673
An instantaneous heart rate meter with digital display.

4. Baker J A et al (1967) — J Physiol (Lond) 188 4-5p
Socially Acceptable Monitoring Instrument.

5. Barnwell P G (1970) — Electronics Components June 1970 681-684
Thick film inductors at VHF.

6. Booyens J and Harvey G R (1960) — Can J Biochem Physiol 38 1301-130 9
The pulse rate as a means of measuring the metabolic rate in man.

7. Bradfield R B et al (1969) — Am J Clin Nutr 22, 696-700
Simultaneous comparison of respirometer and heart rate telemetry technique as measures of human energy expenditure.

8. Caldwell W M et al (1970) — Med Biol Engng Vol 8 pp 181-185
A wide range linear beat by beat cardiotachometer.

9. Corkhill J R and Mullins D R (1969) — RAE Technical Memorandum RAD 877
The properties of thick film inductors.

10. Crowdy J P et al (1971) — APRE Report 2/71
Combat nutrition - The effects of a restricted diet on the performance of hard and prolonged physical work.

11. Czekajewski J and Tove P A (1965) — Med Electron Biol Engng 3,57-63
A cardiotachometer with fast response.

12. Glazier E V D and Lamont H R L (1958) — The Services text book of radio Vol 5 p 267-268 Transmission and Propagation.

13. Gordon J W et al (1972) — J App Physiol Vol 32 No. 5 pp 718-723
Precision digital heart rate meter.

14. Green D G (1967) — Med Biol Engng Vol 5. pp 387-390
A transistor instantaneous frequency meter.

15. Green K (1971) — RAE Technical Report 71037
Design curves for flat square spiral inductors.

16. Grover F W (1946) — Inductance calculations: Working formulas and tables.
D Van Nostrand 1946 New York.

17. Haisman M (1970) APRE Research Report 1/70
The energy expenditure of jungle patrols.

18. Hanish H M et al (1971) Am J Clin Nutr 24 1155-1163
Technical aspects of monitoring the heart rate of active persons.

19. Home Office (1976) LMSC 76/3 Draft Issue 2
Performance Specification:
Medical and biological telemetry devices.

20. Ludwig H (1967) Med Biol Engng Vol 5 pp 615-621
Heart rate meter with digital tuning and linear beat to beat readout.

21. Mackay R S (1963) Med Electron Biol Engng Vol 1 pp 109-111
Instantaneous frequency measurement.

22. Mackay R S (1970) Biomedical telemetry 2nd Edition pp 84-85
Wiley, New York.

23. Murphy K S K (1969) Med Biol Engng Vol 7 pp 543-548
An integrated circuit frequency meter.

24. Rodahl K et al (1975) Inst. Work. Physiology Oslo 3 Norway
Circulatory strain, Estimated energy output and catecholamine excretion in Norwegian Coastal fishermen.

25. Shackel B (1959) Am J Psychol 72, 114-121
Skin drilling: a method for diminishing galvanic skin potentials.

26. Smith W S and O'Brien C (1976) Biochem Engng Vol 11, No 4 128-131
A system for rapid analysis of long term recording of heart rate and other physiological parameters.

27. Wynne R W (1974) APRE Memorandum 4/74
Preliminary tests of agility course Berkshire Copse test site.

Radio Frequency (RF) measurements of the transmitter

Effective Radiated power (erp)

Theory

The power density P_d due to the power radiated by a non-isotropic radiator is given by

$$P_d = \frac{PG}{4\pi R^2} \text{ Watts (1)}$$ (Ref Data for Radio Engineers 1969)

where G = gain of the aerial

P = input power to aerial

the product PG = erp

R = distance from source in meters

also $$P_d = \frac{E^2}{120\pi} \text{ Watts (2)}$$

where E = electric field strength in volts/meter
$\pi.120$ = resistance of free space

from (1) and (2)

$$erp = \frac{E^2R^2}{30} \quad (3)$$

Method

Field strength measurements were made on an open stretch of ground using a Singer Stoddart NM 37/57 field strength meter attached to a Singer biconical aerial for measurements up to 200 MHz and a log-conical aerial 93490/1 for measurements up to 1000 MHz. The calibration of the instrument was checked at regular intervals and readjusted as necessary. The transmitter was placed approximately 6m from the measuring aerial and the field strength of each harmonic was recorded. Aerial correction factors (ACF) were added to each field strength reading (in db above $1\mu V$) and the erp was calculated from equation 3.

Three transmitters were examined.

(1) prototype radio telemeter with adhesive tape copper coil

(2) prototype radiotelemeter with printed circuit copper coil

(3) commercial ecg telemeter crystal controlled (MIE)

The commercial telemeter was examined for interest and to provide a comparison of performance. All measurements were made with the carrier waves modulated and are presented in the following tables.

Prototype telemeter with adhesive copper tape coil				
Frequency (MHz)	Field Strength pk(dB(μV))	ACF (dB)	Field Strength +ACF(dB)$\pm$3dB	erp nW
104.8	49	7	56	477
209.6	56	19.5	75.5	42.5 μW
314.4	42	17	59	953
419.2	25	19	44	30
524	39	20.5	59.5	1069
628.8	7	22	29	0.95
733.6	28	23	51	151
838.4	24	24	48	76
943.2	32	25.5	57.5	675

Prototype telemeter with printed circuit coil				
Frequency (MHz)	Field Strength pk(dB(μV))	ACF (dB)	Field Strength ACF(dB)$\pm$3dB	erp nW
104.8	50	7	57	600
209.6	40	19.5	59.5	1069
314.4	28.5	17	45.5	43
419.2	20	19	39	9.5
524	25	20.5	45.5	43
628.8	33	22	55	379
733.6	36	23	59	953
838.4	14	24	38	7.6
943.2	24	25.5	49.5	106

Commercial ECG Telemeter (MIE)				
Frequency (MHz)	Field Strength pk(dB(μV))	ACF (dB)	Field Strength +ACF(dB)$\pm$3dB	erp nW
102	50	7	57	600
204	22	20	42	19
310	31	17	48	76
408	38	19	57	600
519	25	20	45	38
610	25	22	47	60
722	23	23	46	48
820	25	24	49	95
920	23	25	48	76

The output power of the fundamental carrier waves of both prototype transmitters is within the specified erp of 1mW for "wideband" transmitters in the Medical and Biological Telemeter waveband (Home Office 1976). Apart from the 2nd, 6th and 7th harmonic of the transmitter with the printed circuit coil all spurious emissions (eg harmonics) are below the 250 nW specified by the Home Office.

The MIE Ltd commercial transmitter which was tested gave emissions at 20 MHz intervals over the frequency range 100 MHz-1000 MHz and its erp at 102 MHz was 600 nW. Only the field strengths at the even harmonics were measured in the field but a frequency spectrum was plotted in the laboratory using the equipment described previously.

Spectrum Analysis

The output frequency spectrum between 0 and 1000 MHz was measured on a Hewlett Packard 8554B spectrum analyser using a wire loop as a probe. The frequency spectra of the two prototype transmitters were measured at 5°C, room temperature, and 35°C and are shown in Figures 9 and 10. Figure 11 shows a scan of the modulated carrier wave, from this it can be seen that sideband attentuation is 20dB at 0.05 MHz from the carrier wave resonant frequency and the carrier wave is attentuated 50dB at $\pm$ 0.05 MHz from its resonant frequency.

Frequency stability

The frequency of the RF carrier wave of the two prototype transmitters was monitored on a Hewlett Packard 5340A frequency counter with a loop of wire wrapped around the transmitter case and fed to the 50Ω input of the counter. The resolution of the counter was set to 10 MHz.

Each telemeter was placed in turn in a temperature controlled chamber. The temperature of the telemeter was monitored with a probe attached to the circuit board of the audio oscillator and fed to a Comark digital thermometer. (Accuracy $\pm$ 1°C) Measurements were made at 5 minute intervals over a $\frac{1}{2}$ hour period for temperatures of 5°C and 35°C. At each 5 minute interval the frequency of the carrier wave was recorded for varying supply voltages between 5 and 9V.

The transmitter with the copper adhesive tape coil showed a frequency drift of approximately 1.6 MHz over the temperature range measured. This is thought to be due to the mechanical instability of the coil producing changes in inductance and self capacitance as it expands and contracts over the temperature range. The more stable printed circuit coil, however only showed a drift of approximately 0.36 MHz over the temperature range and supply voltage range of 6-9V. The detailed results of the transmitter with the printed circuit coil are presented in the following table and illustrated graphically in Figure 12.

TRANSMITTER WITH PRINTED CIRCUIT COIL AND TETFER TRIMMER

Time (Min)	Temperature (°C)	Supply Voltage (V)	Frequency (MHz)	Time (Min)	Temperature (°C)	Supply Voltage (V)	Frequency (MHz)	Time (Min)	Temperature (°C)	Supply Voltage (V)	Frequency (MHz)
0	37	9.0	105.067	15	35	9.0	105.076	25	36	9.0	105.076
		8.0	105.067			8.0	105.074			8.0	105.074
		7.0	105.065			7.0	105.074			7.0	105.073
		6.5	105.068			6.5	105.072			6.5	105.072
		6.0	105.062			6.0	105.068			6.0	105.068
		5.5	104.587			5.5	104.609			5.5	104.613
		5.0	103.828			5.0	103.739			5.0	103.749
5	36	9.0	105.075	20	36	9.0	105.074				
		8.0	105.074			8.0	105.073				
		7.0	105.074			7.0	105.072				
		6.5	105.072			6.5	105.070				
		6.0	105.068			6.0	105.067				
		5.5	104.524			5.5	104.531				
		5.0	103.851			5.0	103.744				
0	5	9.0	104.816	15	5	9.0	104.825	25	5.5	9.0	104.819
		8.0	104.816			8.0	104.831			8.0	104.818
		7.0	104.817			7.0	104.828			7.0	104.816
		6.5	104.815			6.5	104.822			6.5	104.815
		6.0	104.806			6.0	104.811			6.0	104.762
		5.5	104.135			5.5	104.124			5.5	104.188
		5.0	103.230			5.0	103.105			5.0	103.089
10	5	9.0	104.825	20	5.5	9.0	104.821				
		8.0	104.831			8.0	104.820				
		7.0	104.821			7.0	104.819				
		6.5	104.822			6.5	104.818				
		6.0	104.810			6.0	104.806				
		5.5	104.214			5.5	104.213				
		5.0	103.230			5.0	103.227				

The test results show that the frequency of the carrier wave remains stable generally within $\pm$ .015 MHz for supply voltages (supply to voltage regulator of transmitter) between 6 and 9 volts. The frequency drift is approximately 0.26 MHz between 15°C and 37°C. At a set temperature and supply voltage frequency drift is on average approximately 0.01 MHz over 25 minutes. The performance of the transmitter with the printed circuit coil falls within the Home Office specification (1976) for frequency stability of "wideband" equipment if tuned to 104.8 MHz at 20°C.

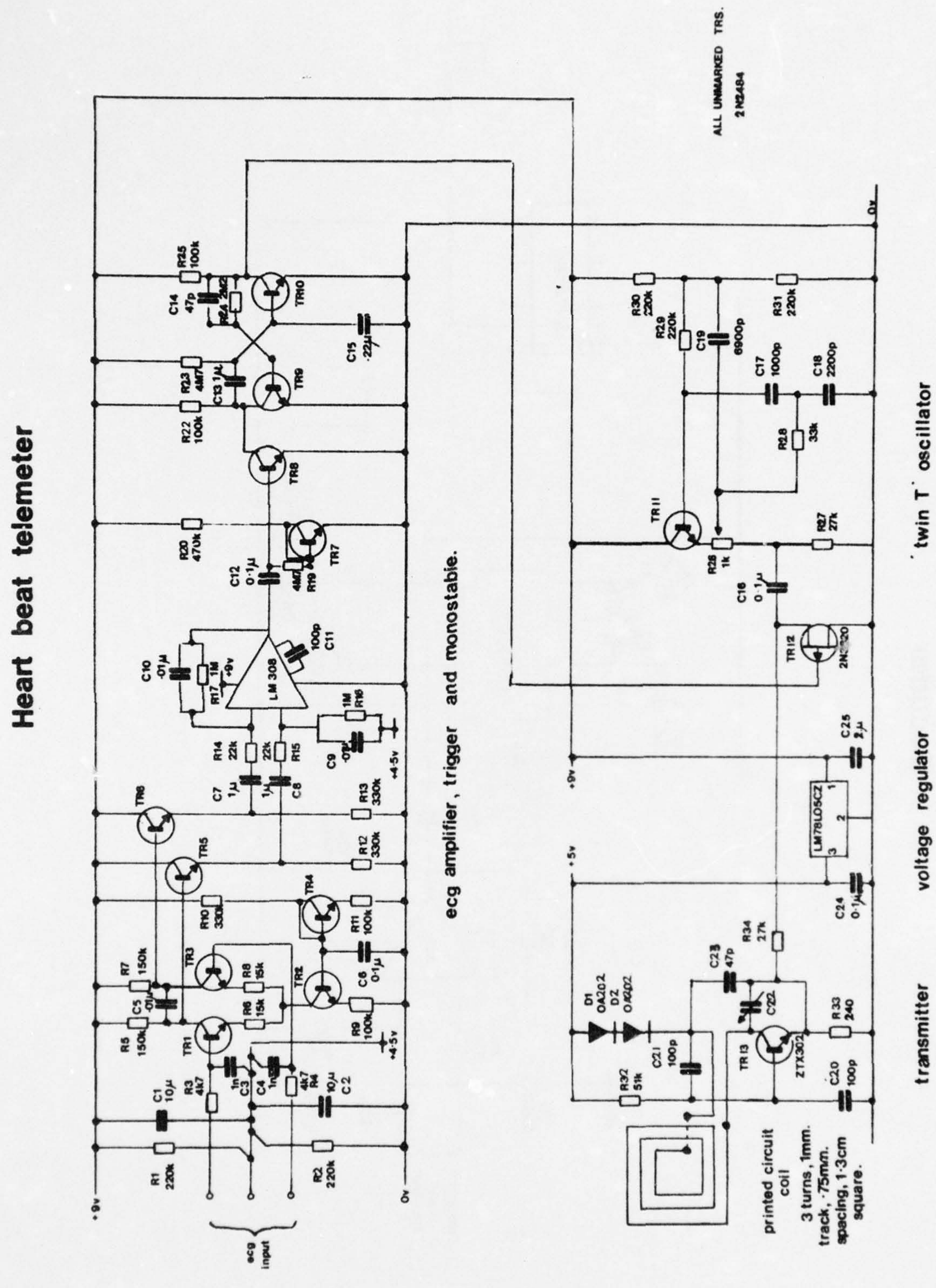

Heart beat telemeter
ecg amplifier, trigger and monostabie.
ecg input
transmitter
voltage regulator
'twin T' oscillator
ALL UNMARKED TRS. 2N2484
printed circuit coil
3 turns, 1mm. track, ·75mm. spacing, 1·3cm square.

FIG 1

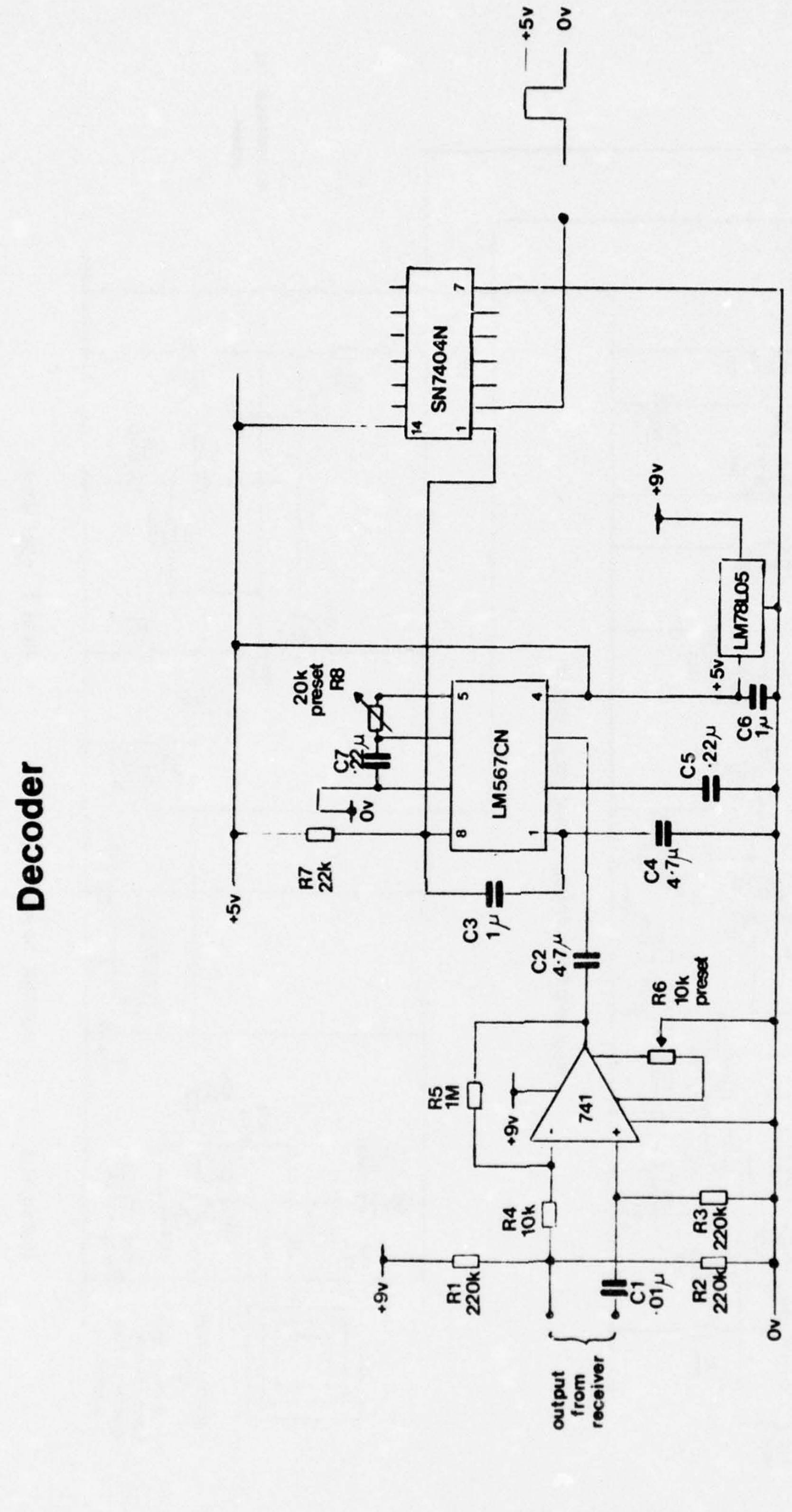
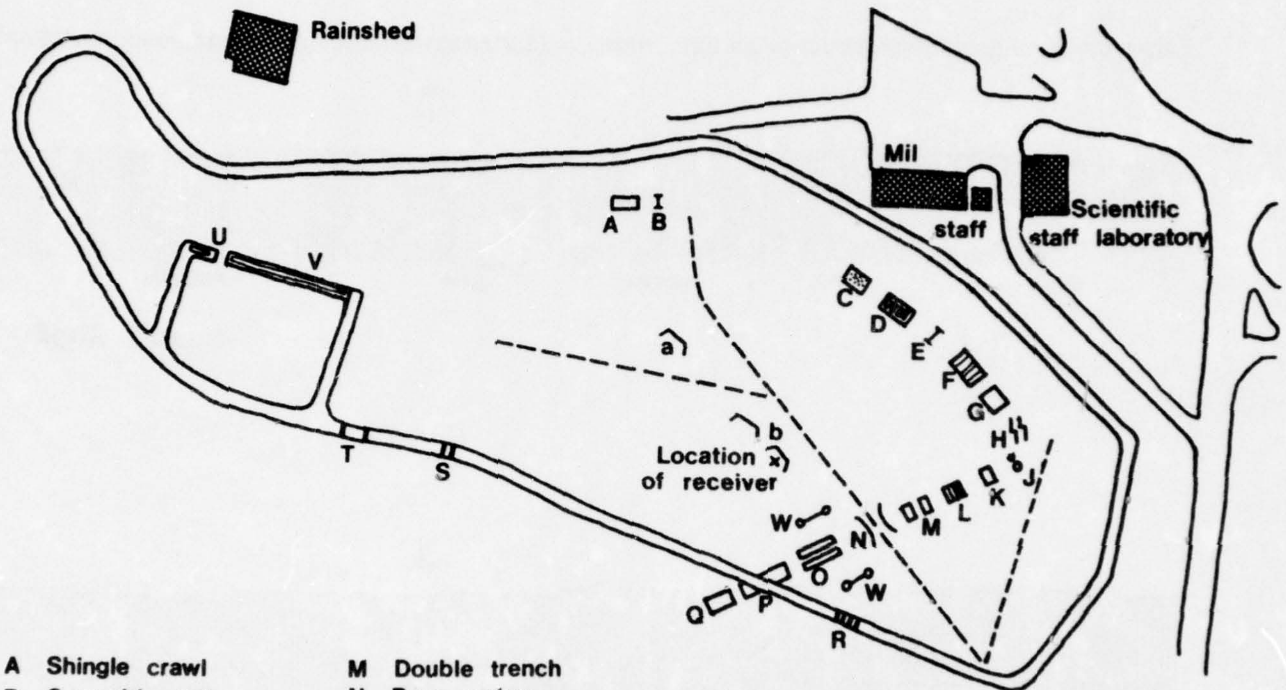

Decoder
+5v
0v
SN7404N
14
1
7
+9v
LM78L05
+5v
20k
preset
R8
5
4
LM567CN
8
1
C7
·22μ
0v
R7
22k
C3
1μ
C5
·22μ
C6
1μ
C4
4·7μ
C2
4·7μ
R6
10k
preset
R5
1M
+9v
741
R4
10k
R1
220k
C1
·01μ
R3
220k
R2
220k
output
from
receiver

FIG 2

Plan of Boot track and agility course



A	Shingle crawl	M	Double trench		
B	Scramble net	N	Rope swing		
C	Forest of poles	O	Pipes		
D	Windows	P	Cat walk		
E	Wall	Q	Monkey swing		
F	Logs	R	Concrete steps		
G	Stepping stones	S	Wooden stile	a	Weapon slit
H	Zig - zag trench	T	Concrete / brick ramp	b	Command post
J	Wall	U	Mud trough		
K	Hurdles	V	Water trough		
L	Ramp	W	Parallel ropes		

FIG 3

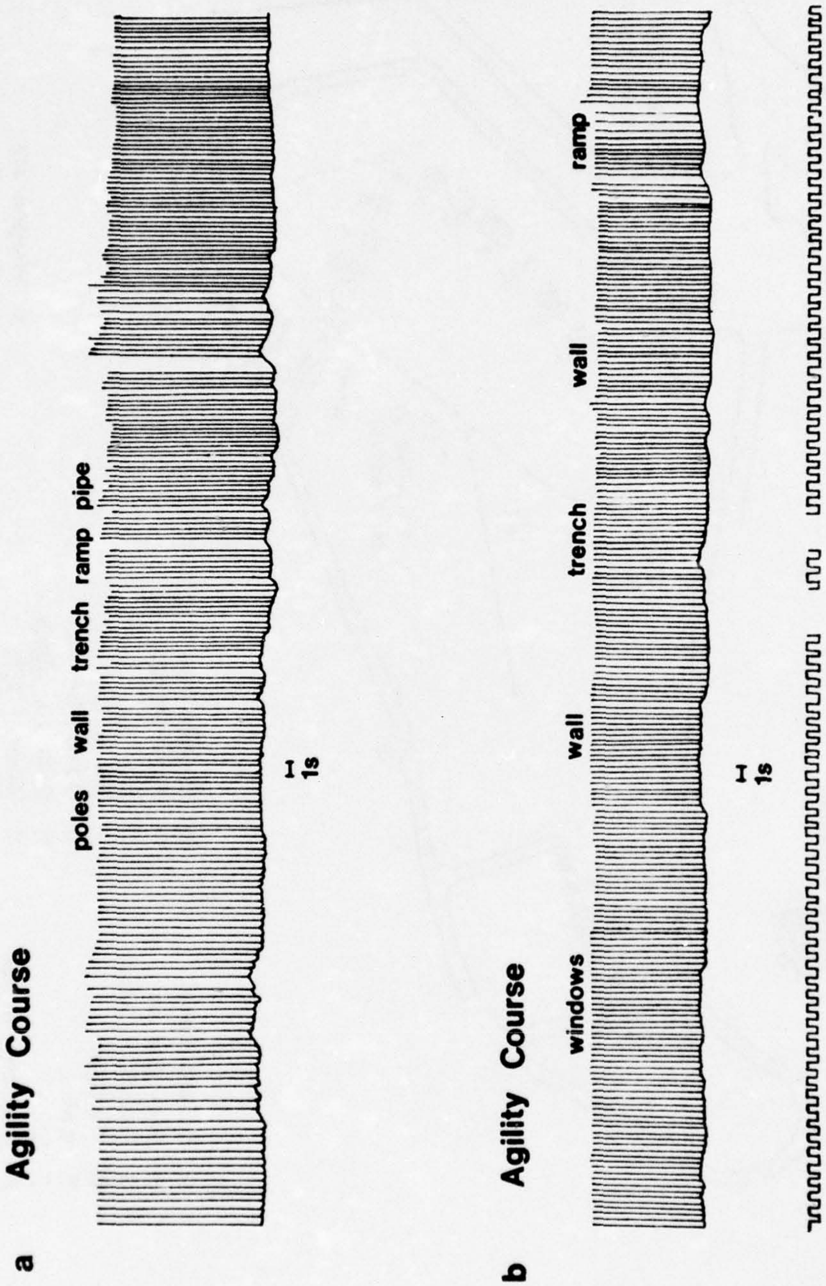

a
Agility Course
poles
wall
trench
ramp
pipe
1s
b
Agility Course
windows
wall
trench
wall
ramp
1s

FIG 4

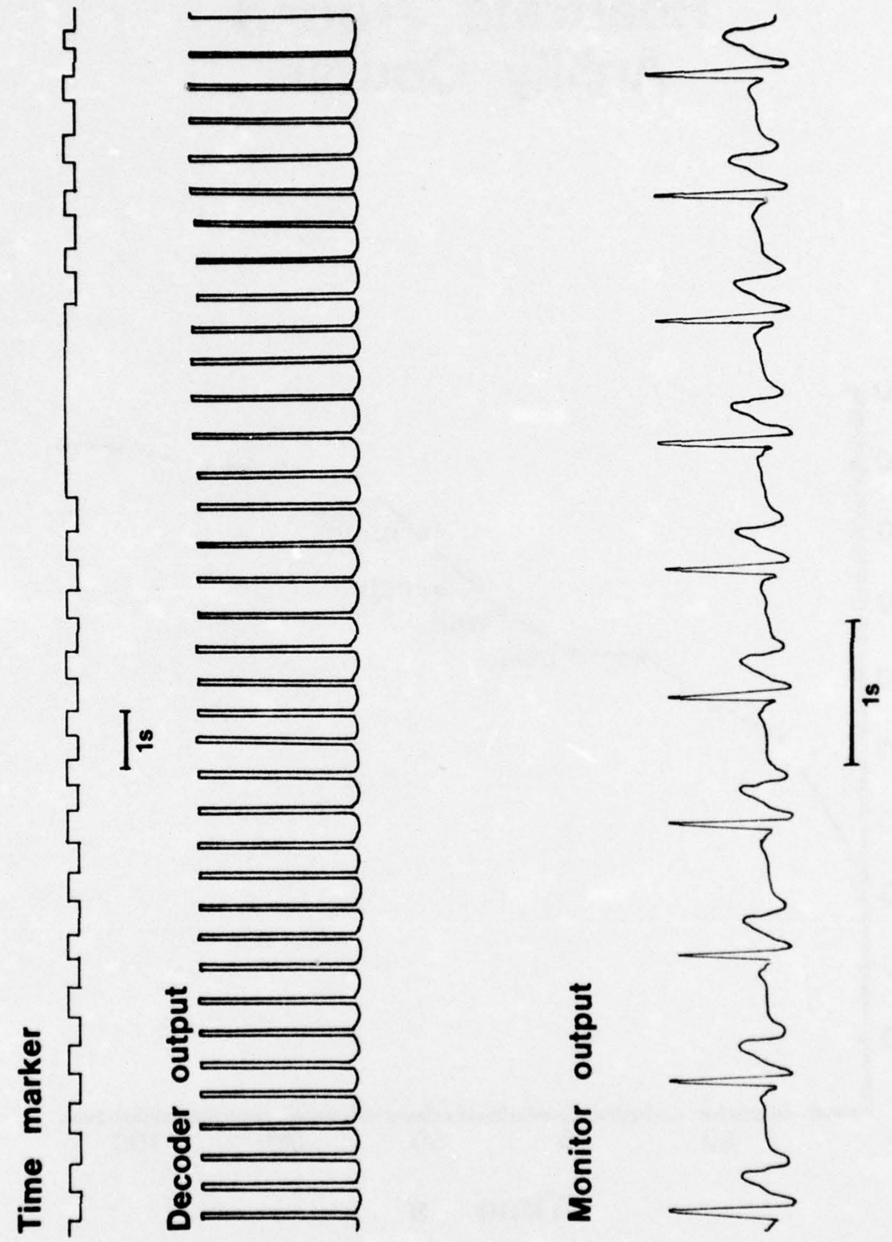


FIG 5

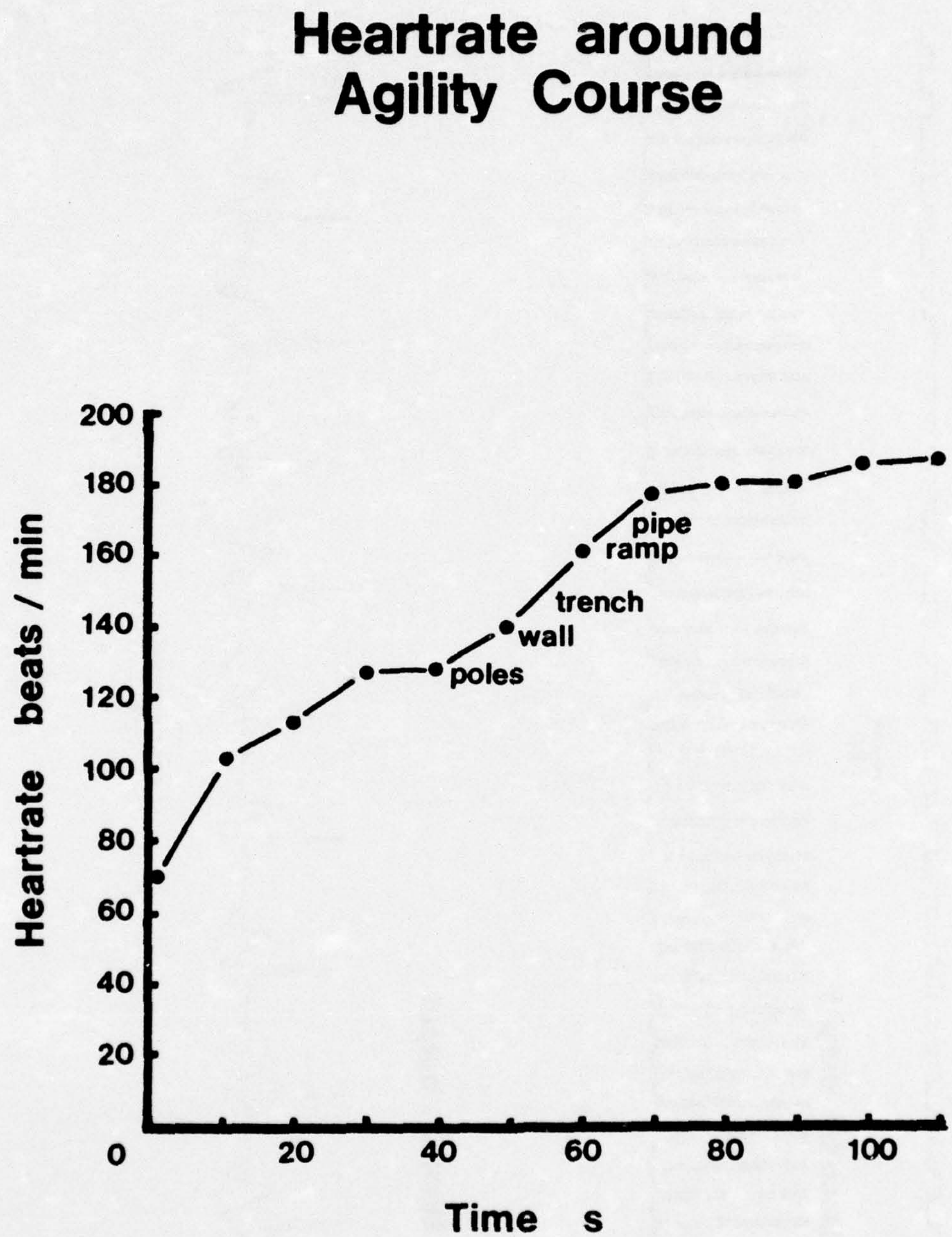

Heartrate around
Agility Course
200
180
160
140
120
100
80
60
40
20
0
20
40
60
80
100
Heartrate beats / min
Time s
pipe
ramp
trench
wall
poles

FIG 6

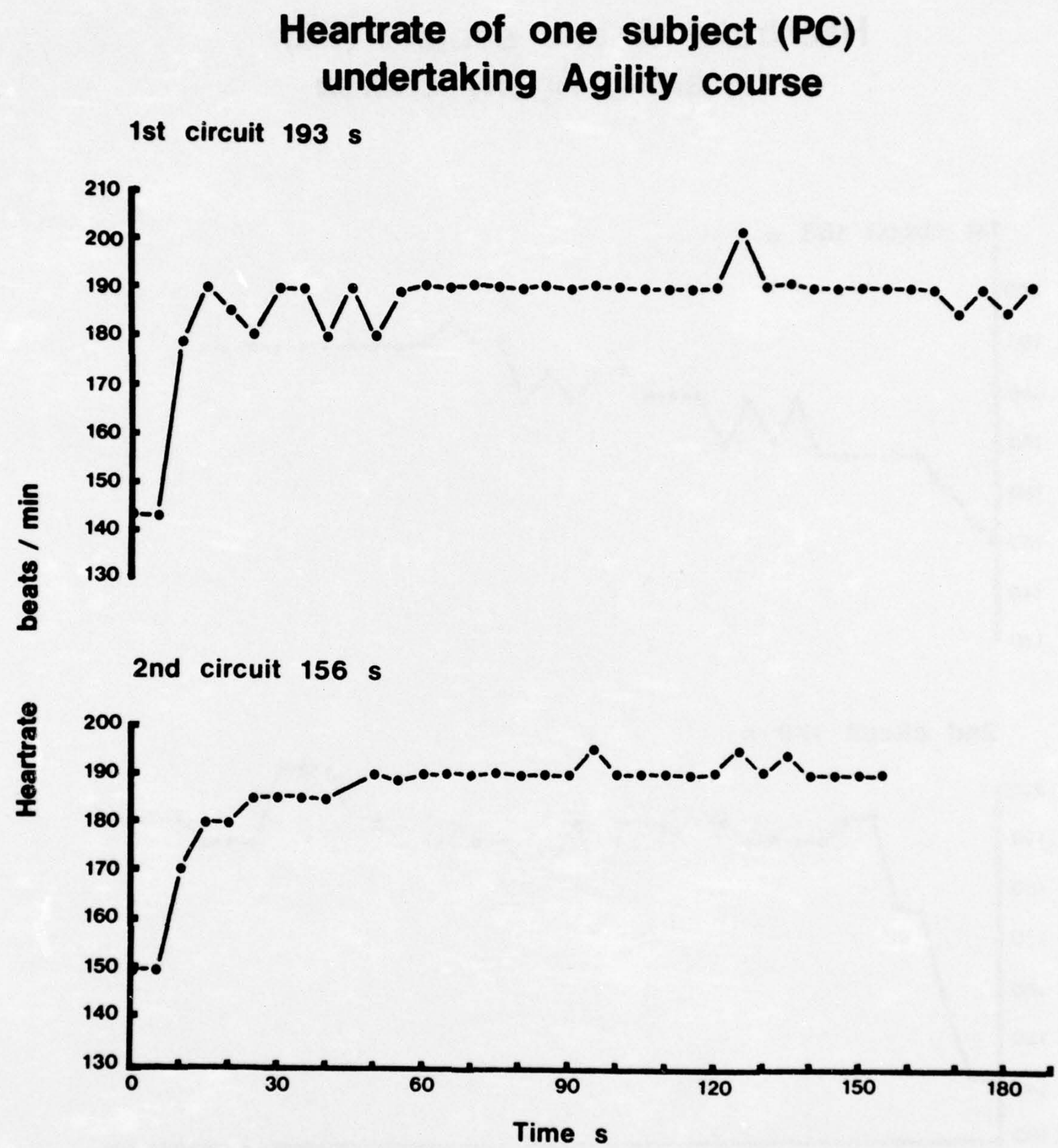

Heartrate of one subject (PC)
undertaking Agility course
1st circuit 193 s
210
200
190
180
170
160
150
140
130
2nd circuit 156 s
200
190
180
170
160
150
140
130
Heartrate beats / min
0
30
60
90
120
150
180
Time s

FIG 7

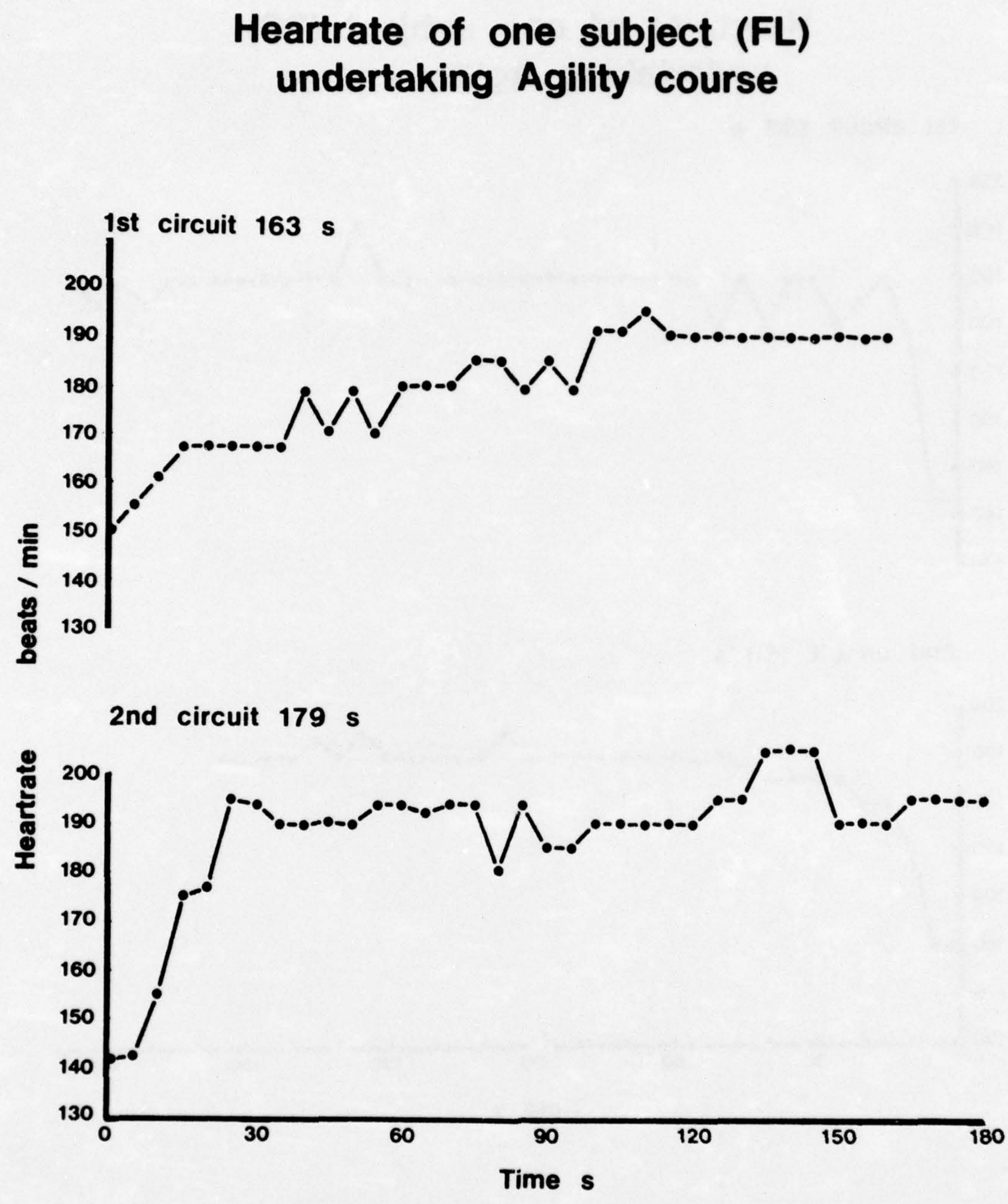
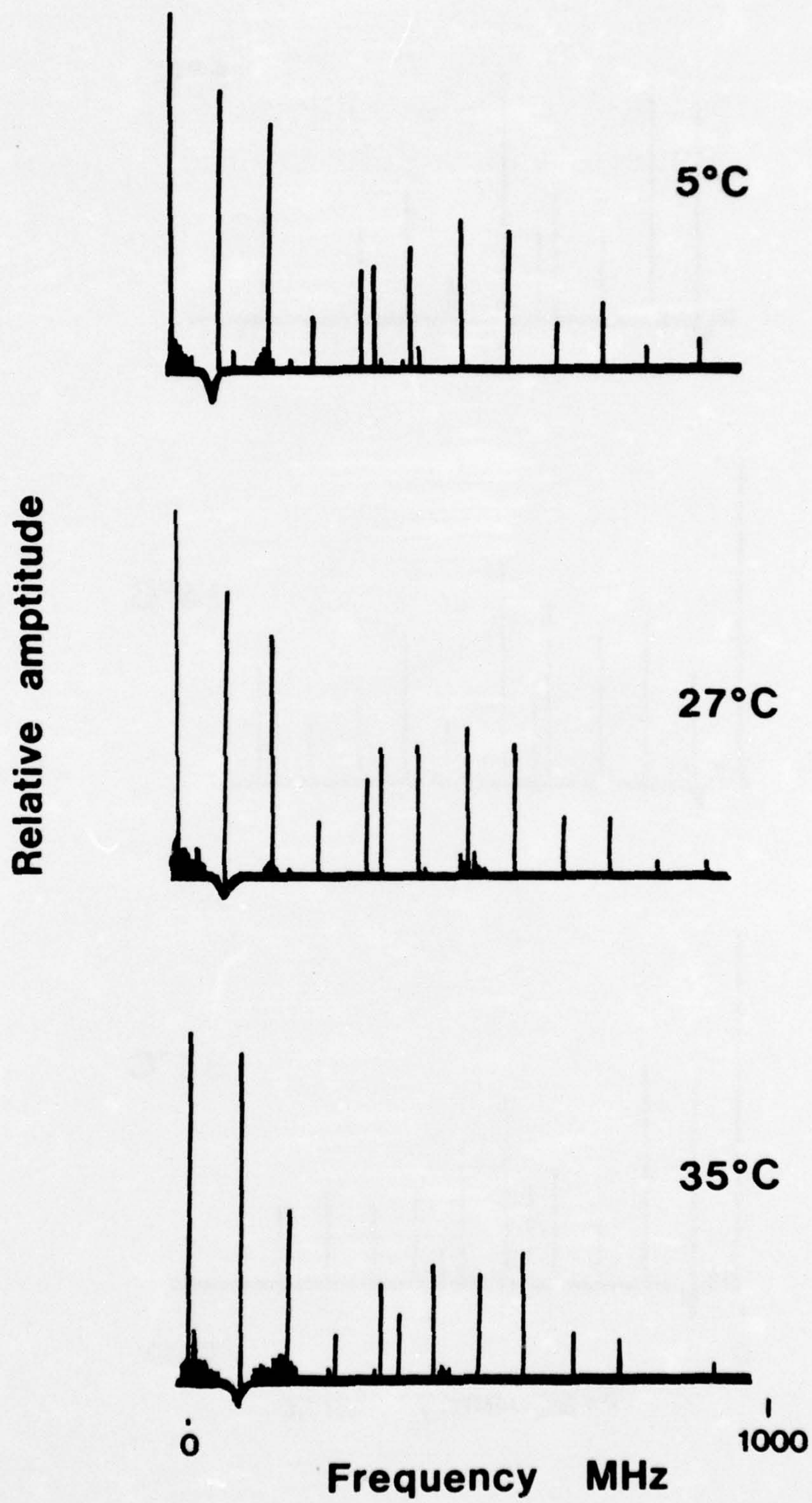
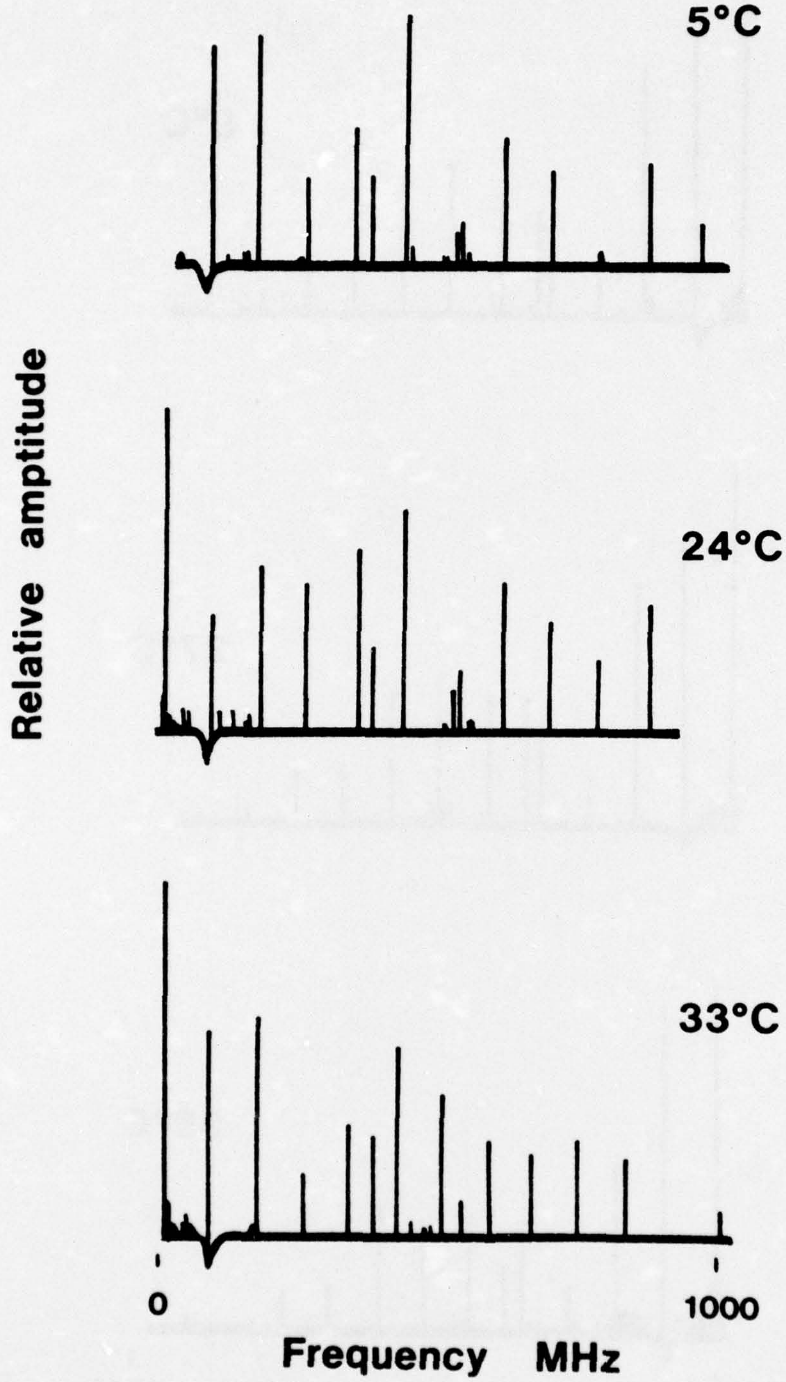

Heartrate of one subject (FL)
undertaking Agility course
1st circuit 163 s
2nd circuit 179 s
200
190
180
170
160
150
140
130
Heartrate beats / min
0
30
60
90
120
150
180
Time s

FIG 8



SPECTRUM ANALYSIS

FIG 9



SPECTRUM ANALYSIS

FIG 10

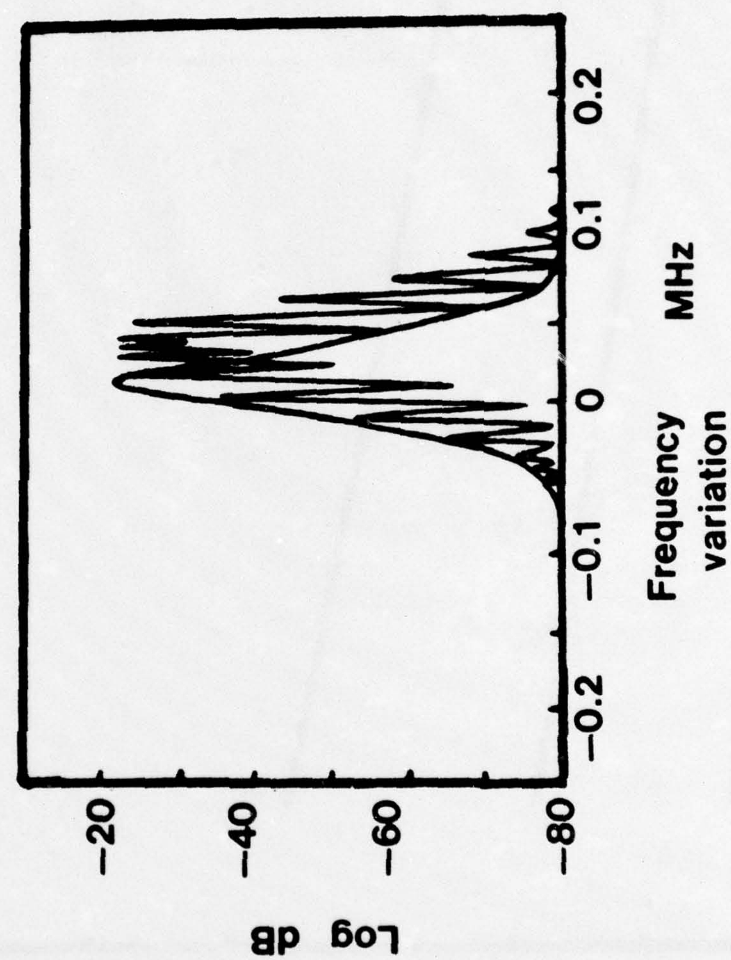
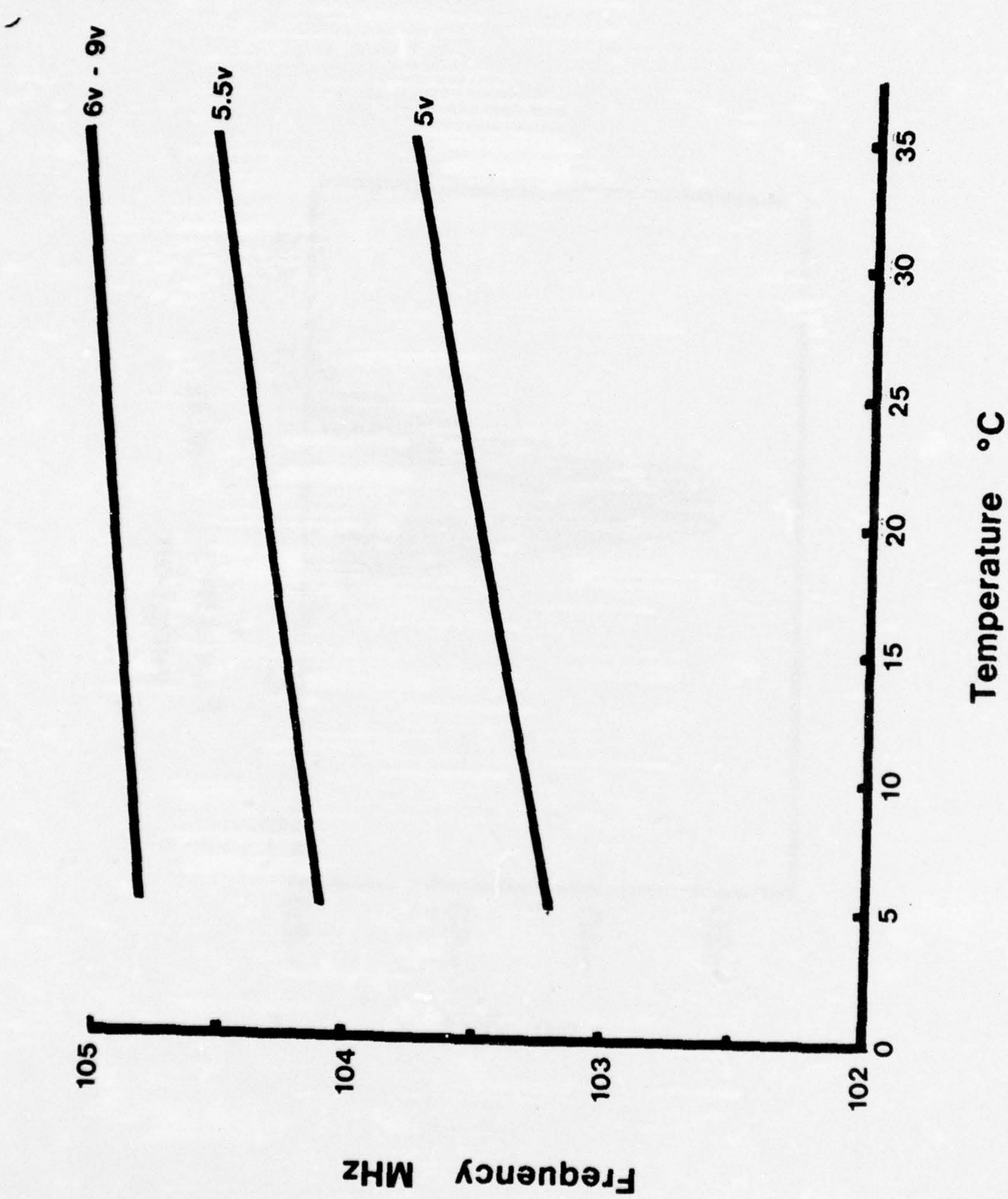


FIG 11



TRANSMITTER WITH PRINTED CIRCUIT COIL

FIG 12

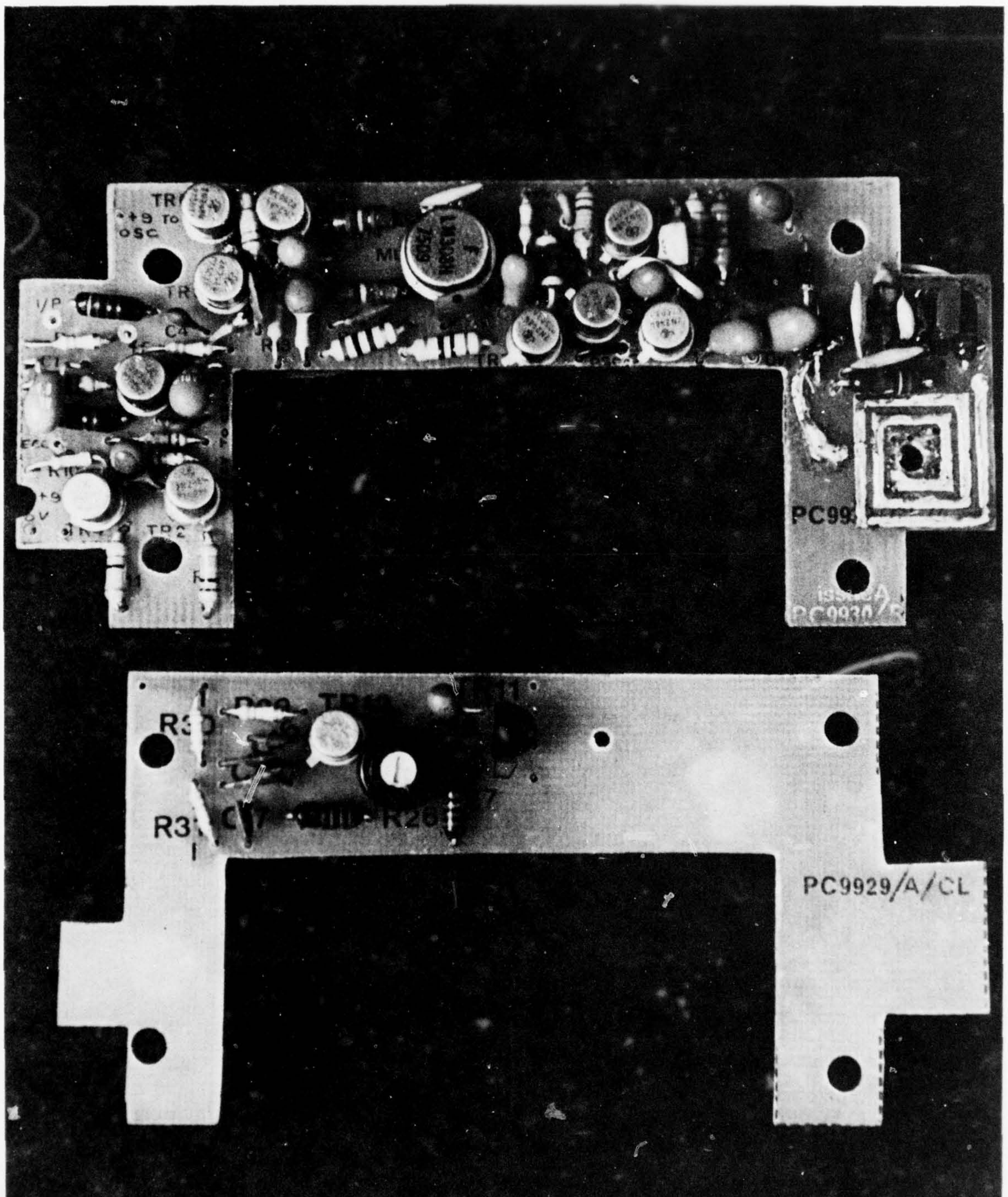


FIG 13

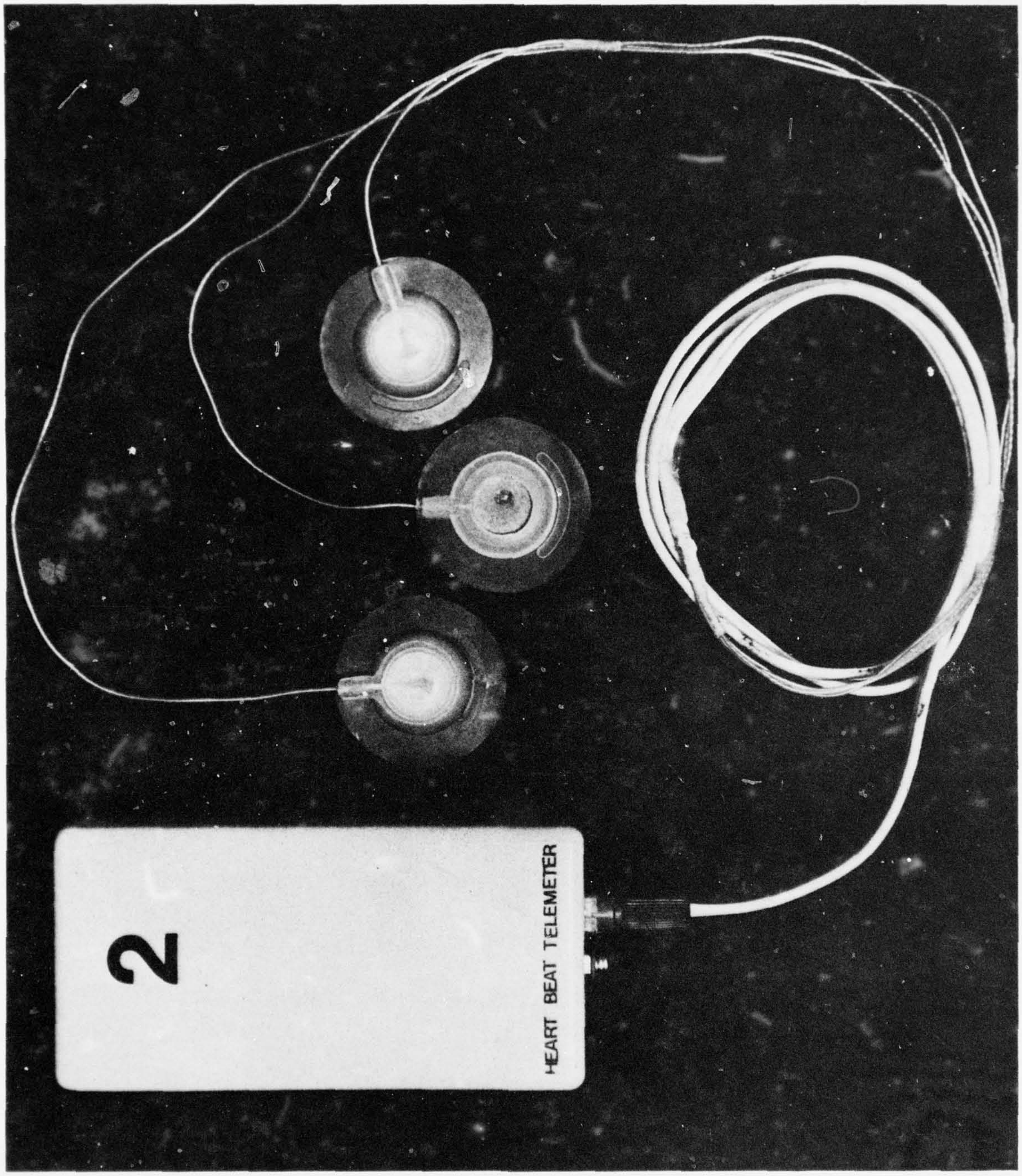


FIG 14

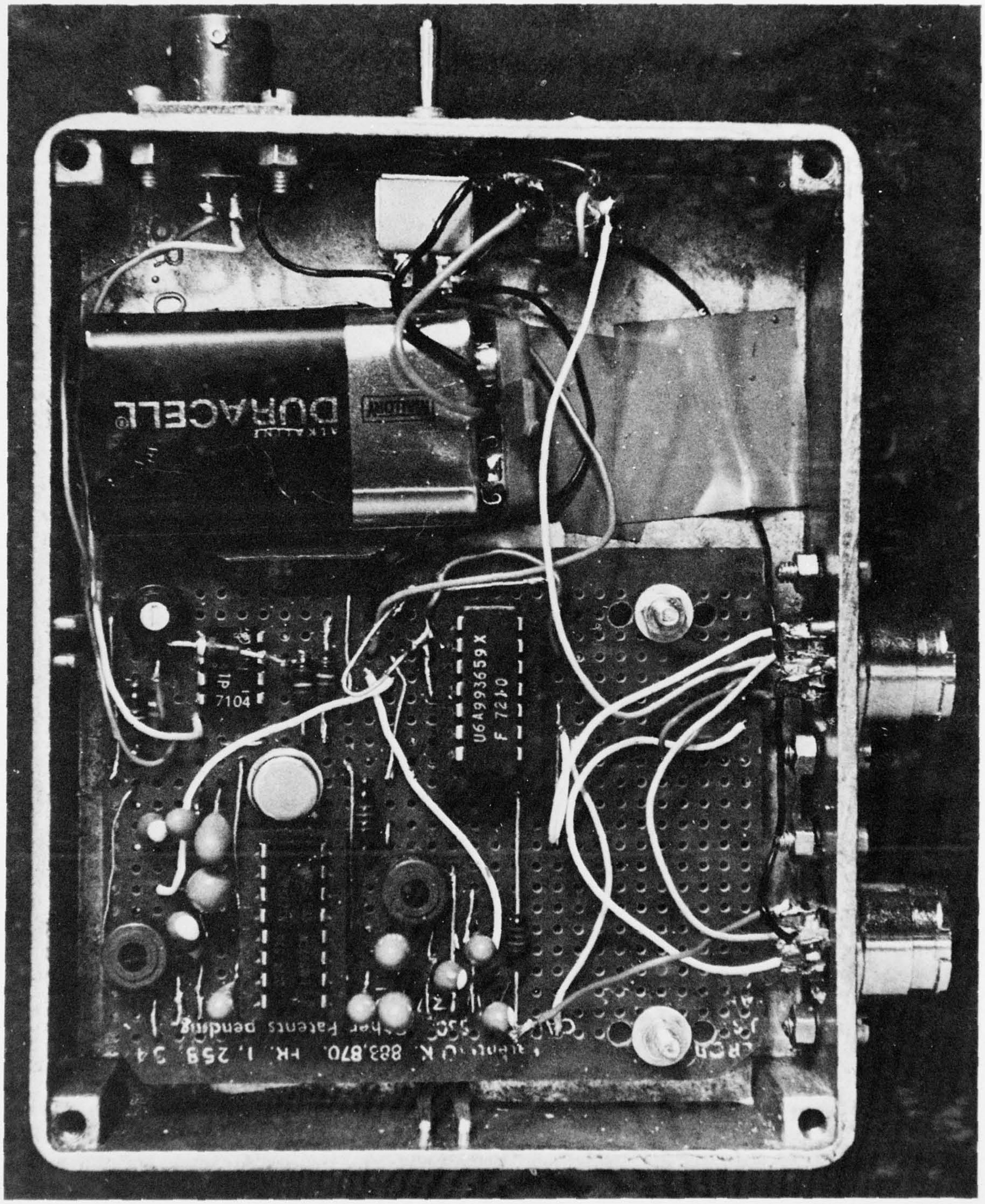


FIG 15

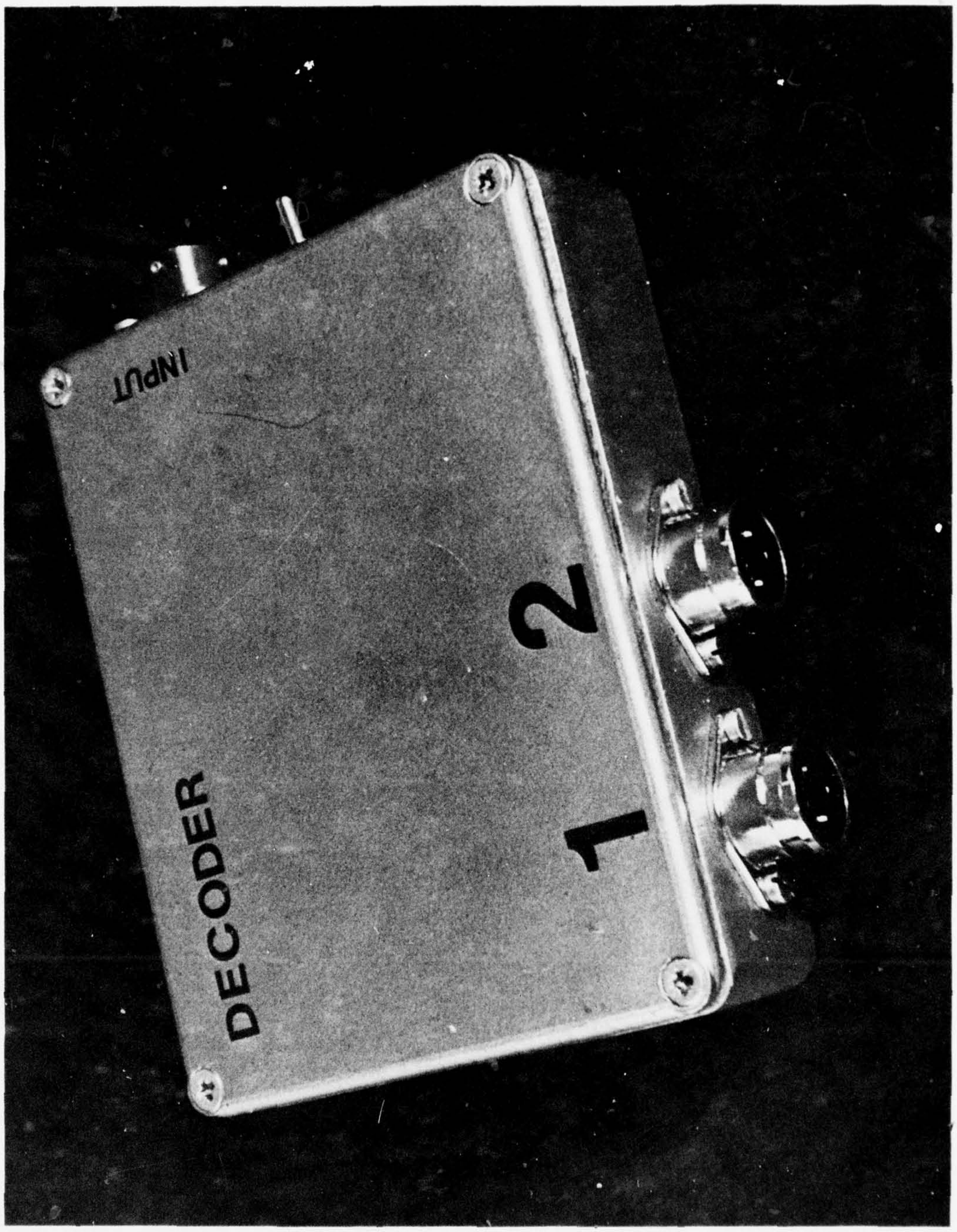


FIG 16

DISTRIBUTION LIST

MINISTRY OF DEFENCE	No. of Copies
Army Department	
CS(A)	1
DCS(A)	1
AD/SAG(A)3	1
SAG(A)3b	2
DCD	1
ACGS(OR)	6
DAT	1
IPAT	1
DAHR	1
DCT(C&T1)	2
Sec CCD(OCCE) C&T1d	
Central Staffs	
MOD Library	2
Navy Department	
SP(N)	1
MDG(N)	1
Air Force Department	
DHR(RAF)	1
Sec FPRC	1
Procurement Executive	
DR/CB	1
AD/AE	1
DRIC	2
Arms, Directors, Schools, Establishments, Commands	
HQ SO in C	1
School of Army Health	1
RAM College (1 for Professor of Army Health)	2
Staff College (TDRC)	1
RMCS	1
RMAS	1
CDE	1
SCRDE	1
DOAE	1
RAE (EP2)	1
RSRE(C)	1
IAM	1
INM	1
Royal Navy Physiological Laboratory	1
ASPT	1
A Man SG (WS)	1

	No. of Copies
Overseas Liaison	
BDLS Ottawa	1
BDLS Canberra	1
BDLS Washington (including 1 for DR and DS, 1 for Med Rep and 1 for SMO/BNS)	4
MINISTRY OF AGRICULTURE, FISHERIES AND FOOD	
FS & FD, Food Research Institute, Norwich for the CDSO Food Study Group	12
MEDICAL RESEARCH COUNCIL	
Assistant Secretary APRC	7
Sec RNPRC	2
MRC EPU	1
STANDARDIZATION AND LIAISON STAFF IN UK	
Canadian Forces Liaison Officer (ACGS(OR))	4
Canadian Forces Defence Research Board Member, London	1
Australian Army Liaison Staff	4
OCO for India	6
Senior Army Liaison Staff New Zealand Army	2
US Army Standardisation Staff	15
Med Rep Defence Attache's Office, US Embassy	1
MA Swedish Embassy	1
CONSULTANTS TO APRE	
Dr Passmore	1
Dr Durnin	1
MISCELLANEOUS	
DCIEM Ottawa (Major O'Hara, Major Allen)	2
Anglo-French Defence Research Collaboration in Human Factors DRME Biologie	1
USARIEM (Dr Goldman, Dr Vogel)	2
Medical Director BMVg (Dr D J Jovy)	1
LAIR	1
Institute of Physiology and Allied Sciences, Delhi Cantt, Delhi (Surgeon Commodore Malhotra)	1
Arbeidsfysiologisk Institutt Oslo, (Professor Rodahl and Dr Hermansen)	2
NMRI Bethesda	1
Australian Forces Food Science Establishment	1
APRE Library	2